00080280

THE
ASIATIC SOCIETY OF BOMBAY
TOWN HALL, BOMBAY-400 023.

Digitized with financial assistance from the
Government of Maharashtra
on 23 March, 2016

AN

ENCYCLOPÆDIA

OF

CIVIL ENGINEERING,

HISTORICAL, THEORETICAL, AND PRACTICAL.

8.0280
ac

BY

EDWARD CRESY,

Architect and Civil Engineer.

R. d. 2

ILLUSTRATED BY

UPWARDS OF THREE THOUSAND ENGRAVINGS ON WOOD,
BY R. BRANSTON.

IN TWO VOLUMES.

VOL. II.

LONDON:

PRINTED FOR

LONGMAN, BROWN, GREEN, AND LONGMANS,

PATERNOSTER-ROW.

1847.

R
624.03
Cre/Ene
80280

CHAP. IX.

VALUATIONS OF PROPERTY.

In forming a valuation of either land or houses great attention should be paid to their locality, as well as to their quality. Land is not uniform in this particular, as it consists of several varieties; and it is necessary, when surveying an estate, so to apportion it, that land of the same description and value be classed under the same head or denomination: where the soil, however, differs materially in the same enclosure, this is not very easily to be done; but in all cases, it must be noticed what are the proportions of the good to the bad, and valued accordingly. Not only the nature and depth of the soil, but the quality of the subsoil should be thoroughly examined by digging into it, and the description fully entered in a book prepared for the purpose; for if the valuator is governed by the appearance of the crops, and forms his opinion of the value of the land by the quality and quantity of produce, he will often err, by putting a high price on light or bad land highly manured; which is unjust, inasmuch as this value is only temporary, and dependant upon the skill and capital bestowed upon it.

Pasture Lands in their value depend on the quality of the herbage; and on them, as well as on all tillage lands, the nature of the prevalent indigenous plants should be noticed, as they almost always indicate a particular quality of soil and subsoil, and are often much better tests of the quality than by digging at the surface, or sinking holes. Woods and plantations should be estimated according to the agricultural value of the land on which they grow, without reference to the timber and uncultivated lands: in valuing land, it is always better at the commencement to put the price which it is worth under ordinary circumstances, and afterwards to add or diminish according to those which are local, and which are dependant upon elevation, steepness, exposure to injurious winds; different varieties or patches of soil, ill-shaped fields, bad fences, and the state of the roads, &c., &c. Climate in a great degree depends upon elevation; in mountainous districts, not only must a deduction be made for height, but also for situation, whether upon interior or exterior declivities, the climate being much more moist in the bosom of the mountain, and more liable to frost and snow than on the exterior at the same elevation. When lands are so steep and hilly that they inconvenience the farmer in ploughing, manuring, &c., a deduction of from one to four shillings per acre should be made: and where it is too steep to plough, and must be cultivated by the spade, it may be valued as under pasture: considerations should also be made when large stones or rocks produce difficulties in the way of the plough. The character of the prevailing winds should be well ascertained, as they affect the crops; if the land varies in quality, they will not ripen at one and the same time, and for such situations a proper reduction should be made: land in an ordinary situation, within 3 or 4 miles of a market town, with good roads, and not particularly sheltered or exposed, or remarkably level or hilly, and whose greatest elevation does not exceed 300 feet above the level of the sea, the chief matters which are required to be taken under consideration are the means of obtaining manure or limestone, which adds to or diminishes the value. The neighbourhood of large and populous cities also affects the value of land, and the distance must always be noticed, as well as the local advantages or disadvantages obtained; the distance from market, and the difficulty of access, materially lessens value, and ought always to be taken into account.

The soils are usually classed as either clay, sandy, or calcareous, or compounds of one or all, except where composed of peat or the primitive earths, which contain saline compounds and the oxide of iron; such always retain water.

Argillaceous Earth forms the basis of clay, and is usually combined with siliceous sand, as in potter's and pipe-clay, where the proportions of sand are 60 per cent.: clay used for brick-making is not only combined with siliceous but also with calcareous earth, the siliceous most abounding; the colour of this kind of clay is either yellow, blue, brown or red, which it derives from an oxide of iron.

Siliceous Earth is found pure in the flint and in transparent siliceous sand; the colours of the varieties are dependant upon the different proportions of oxide of iron.

Calcareous Earth or Lime is sometimes in the form of limestone, where pure lime is combined with carbonic acid in nearly equal proportions, or in a state combined with sulphuric acid, when it is called gypsum. Calcareous earth may always be detected by pouring a few drops of oil of vitriol or diluted muriatic acid on a small portion, and

if the soil contain lime an effervescence will take place, by the briskness and duration of which the proportion of lime contained in it may be ascertained; but where it is necessary to know the exact quantity of lime in an earth, this may be found by putting half an ounce of the soil into a glass, and pouring upon it dilute muriatic acid, letting it stand for four-and-twenty hours; after which pour off the clear liquid, adding water and stirring it: when the earthy matter has subsided, pour off the clear water, and suffer the residuum to dry till it acquire the same consistence it had previous to pouring on the dilute acid; when weighed, whatever it has lost in weight will be the proportion of lime contained in the soil. For practical purposes, however, the valuator may divide the argillaceous soils into clayey, clayey loam, and argillaceous alluvial: the siliceous soils into sandy, gravelly, slaty, rocky, &c.; the calcareous into limestone, limestone gravel, chalk, and marl: the peat into moor, peat, and bog.

Clay, when either blue or yellow, and in its quality tenacious or lying upon a retentive subsoil, is nearly unfit for tillage; while on an open subsoil it is capable of improvement, and when clays contain a due admixture of sand, lime, and vegetable matter they are well suited to the growth of wheat, and may be classed among the most productive: such may degenerate into a cold stiff clay when there is little or no sand or vegetable matter, and their value is diminished accordingly.

Loamy soils are a compound of argillaceous and siliceous earths, and frequently contain some proportion of lime and vegetable as well as animal matters; from being friable they are soon reduced to a finely pulverised state: when a fine loam is mixed with sand, gravel, clay, or peat, it is to be so designated, and the term loam is only to be understood as comprehending soils of a fine tilth, not forming clods when ploughed in wet weather.

A stiff clay, with either sand, peat, lime, chalk, or stable manure added to it, in the course of time will become a rich loam, but it is only by numerous ploughings and exposure to frost that a due mixture can take place.

A strong clayey loam contains about one-third part and sometimes more of clay, the other ingredients consisting of sand, gravel, lime, &c., the sand predominating.

A friable clayey loam contains less clay and more sand: such a soil is easily cultivated in wet weather.

Sandy or gravelly loams are those where either predominates; both render the soil open and free, though not sufficiently retentive of moisture.

Argillaceous alluvial soils, usually on the banks of great rivers or near the sea-shore, are evidently derived from the deposits of water: they are composed of fine argillaceous loam, or other earths arranged in layers, with alternate beds of clay, shells, sand, &c. The value of these soils depends in a great measure on the quantity of lime they contain.

Rich alluvial soils are the most productive of any when not subject to floods.

Siliceous soils comprise sands of all gradations from open sandy loam to pure sand: white shelly sands, when near the sea, are very productive, although there is not a great portion of earthy matter found in them.

Gravelly soils are those where coarse sand or gravel abounds; a due admixture of loam renders them sufficiently retentive of moisture; such produce excellent crops.

Slaty soils occur on the sides of mountains, and are composed of the debris of slate rock either coarse or fine-grained.

Rocky soils are found abounding with fragments of rock intermixed with mould, where the substratum is rock.

Calcareous or limestone soils contain an unusual quantity of finely pulverised limestone; these form excellent grazing lands.

Limestone gravel soils occur in limestone districts; these are sometimes calcareous and often composed of calcareous sand.

Marly soils consist of two kinds; that which contains clayey marl or calcareous matter combined with clay and white marl, which is a deposit from water, usually found at the bottom of lakes and rivers.

Moory, peaty, or boggy soils vary in their quality; some contain very little earthy matter, and when burnt the ashes which remain scarcely amount to a tenth or twelfth of the original weight; the value of peat soils is dependant upon their production of red or yellow ashes when burnt: in deep bogs these are light and white, and do not amount to more than an eightieth part of the original weight, and are of little use as a manure.

Where peat earth yields a small quantity of white ashes its value is trifling, unless covered with a heavy coat of loamy earth or clay; a solidity is then given to the soil, and crops may be produced upon it.

It is of the utmost importance that due attention should be paid to the nature of the soil, and of all the ingredients of which it is composed; and the person who has to fix a value should thoroughly understand what is meant by the following terms, and should so arrange his field-book that the whole of the lands surveyed should come under one or other of these qualities.

Stiff, when the soil contains above one-half of tenacious clay, and which in dry weather

cracks and opens, and has a tendency to form into large and hard lumps when ploughed in wet weather.

Friable, where it is loose and open, as sandy, gravelly, and mcory lands.

Strong, where a considerable portion of clay abounds, and there is a tendency to form clods or lumps.

Deep, where the soil exceeds 10 inches in depth.

Shallow, where the depth is less than 8 inches.

Dry, where the soil is friable and the subsoil porous.

Wet, where the soil or subsoil is tenacious, or where springs are numerous.

Sharp, where there is a moderate proportion of gravel.

Fine or soft, where there is no gravel, but chiefly composed of fine sand or light earth without gravel.

Cold, where the soil rests on a tenacious clay subsoil, and has a tendency when in pasture to produce rushes and other aquatic plants.

Sandy or gravelly, when either abound.

Slaty, where that substratum is intermixed with the soil.

Worn, where the soil has been long under cultivation without either rest or manure.

Poor, where the land is of a bad quality.

Hungry, where there is a considerable proportion of gravel or coarse sand resting on a gravelly subsoil: on such lands manure does not produce the usual effect.

Colours of soils should also be noticed, as well as the inclination of the various lands: all these qualities, however, for the purposes of valuation may be classed under five heads, as, A, prime land, rich loamy earth; B, medium; C, poor clayey, shallow or stony arable; D, cultivated moors; and E, natural pastures, &c.: and each of these letters may again be subdivided into No. 1, 2, and 3; so that A 1 down to E 3 may comprise every quality found upon an estate or within a district, and a value proportioned accordingly.

The valuator should also be aware that in mountain districts the farmers usually divide their pasture lands into two qualities, called inside and outside grazing, to which is sometimes added another called the remote. The quality and quantity of the herbage must be ascertained, as well as the usual price paid in the neighbourhood for grazing.

Valuation of Houses.—The value of a house depends partly upon what it would reasonably let for by the year, and upon the state of repair in which it may be found: all dwelling-houses with the outbuildings dependant on them are valued as one building; but, as in the country houses are seldom let separate from the land, and there is some little difficulty in coming at a fair letting value, it is advisable to establish a table which, when the dimensions of the buildings are ascertained, may indicate the value: this ought to be well considered, and the state of the repairs noticed before any building is classed in it. New buildings, those that are neither new nor old, and old buildings, have a different value; and the table must be so made as to meet these three denominations: after the number of cube feet in each building is ascertained, its value may be estimated by reference to the price per cube foot determined upon, which price must depend upon circumstances, and upon the judgment of the valuators. The table of value should embrace every class and variety of dwelling-house, as well as the different denominations of offices and outbuildings. To ascertain the cubical content of a building, measure its length, breadth, and height, multiply them together, and enter the product into the field-book for future calculation: it is, however, as well to note what the valuator supposes such a house or premises would let for by the year in any ordinary situation, as a check to his estimate: large houses in the country ought not to be so calculated, as it rarely happens that they let for any thing like their value; the smaller the tenement the more probability there is of a tenant, and of obtaining a return for the outlay or cost of the building.

Houses or mansions belonging to an estate are of little worth when the lands are taken from them; and in making an estimate of such property, there are numerous considerations before a just value can be put upon them: where houses are situated in a town, it is only necessary for the valuator to note down the variety of situations, as the leading streets, squares, &c.; then those in the next and succeeding degrees; supposing he commences with the main or chief street, and continues his survey till he has comprised all the larger houses, and the smaller tenements in the courts and alleys, he must proceed with the yards, warehouses, manufactories, wharves, and other establishments, taking care to class them all under their various and respective heads: the cubical dimensions of the buildings being ascertained, and the area of the premises, a just classification as to locality and value is then required. When the tenant has a lease obliging him to keep the premises in repair, certain allowances are to be made; and in all smaller tenements let by the week or year, some allowance must be made for loss of rent, and for greater wear and tear.

In large cities, towns, villages, and hamlets, the value of property, particularly houses, varies: after the valuator has satisfied himself upon the terms at which the various classes of houses or tenements are let, he will have no difficulty in arriving at a close approximation; in all these cases considerable knowledge and judgment are required, and these kind of

valuations should never be entrusted to the uninitiated, or to those who have not made buildings their particular study.

Mills and buildings, where there is water-power, require to be valued under two heads: first, the buildings by their cubical content; then the water-power; to establish that of the latter, it must be first ascertained whether the water acts by its weight or gravity, as with a breast or overshot wheel, or by impulse, as in undershot wheels. In the former, or gravity wheels, their diameter must be ascertained, as well as the breadth, the depth of the shrouding, and the number of buckets; also the velocity of the wheel, or the number of revolutions it makes in a minute when at work; the fall of water perpendicularly, which is the difference of level between the centre of the column of water as delivered on the wheel and its lower periphery: the section of the water in the trough where it is conducted to the wheel, and its velocity, must be determined by ascertaining the number of seconds a floating body requires to pass through a given distance. In undershot water-wheels, their diameter must be taken, the breadth, the depth of the floatboards, and their number; also the velocity of the wheel, its fall, and the section and velocity of water in approaching the wheel.

In Corn and Flour-mills the valuator must examine their actual state, and whether the millstones are new or old, whether the mills are ever stopped by back-water in floods, or retarded from other causes: in estimating the value, the power of a horse is equal to raising 33000 lbs. 1 foot high in a minute. One pair of millstones in a flour-mill, with its attendant bolting and other machinery, worked by a water-wheel, is considered to be equal to an 8-horse power. The value of the water-power capable of working a pair of millstones with the attendant machinery night and day all the year round, in some situations is valued at 20*l.* per annum, and sometimes more or less, according to circumstances. The full amount of working time is usually taken at twenty-two hours during the day and night, two hours being allowed for the change of men and other contingencies: millstones not actually at work should not be counted. It often happens that a mill has abundance of water for only six months in the year, and is at a considerable distance from a market town; wherever this is the case, and land carriage is considerable, an allowance must be made for every mile of additional distance of a shilling or more in the pound; where a mill is 10 miles from a market town, it can be rarely worked to advantage. To determine the value of a flour-mill, the number of pair of millstones usually worked at a time must be ascertained, as well as their diameter. The force necessary to work a pair of corn millstones grinding meal, together with a pair of shelling and attendant machinery, is taken sometimes at only 6-horse power: the number of pairs of grinding mill-stones, shelling-stones, and other machinery in the mill, as well as the ordinary working time, must be also ascertained. To determine the water-power of corn-mills where there is one pair of stones, tables are usually made, calculated upon the performance of an 8-horse power engine.

Bleaching Mills. In beetling mills in a single long engine the wiper beam, or that which is furnished with cogs for lifting the beetles, is usually 10 feet long, and makes 30 revolutions in a minute; being furnished with two sets of cogs on its circumference, it raises the beetle sixty times in a minute; such a wiper beam working beetles of 4 feet 4 inches in length, and 3 inches in depth from front to rear, making thirty revolutions, or lifting the beetles sixty times in a minute 1 foot high, is equal to one-horse power. In this calculation the power necessary for working the traverse beam, which holds the linen, is included; an allowance is made for the guide slips, which retain the beetles in a perpendicular position.

Tables may be made upon the above data for any length of beetles, where the number of inches from front to rear are given; and the horse-power may be set down. To determine the value of the other machinery in a bleaching mill, it is usual to consider a pair of rub boards equal to two-thirds of a horse-power; a pair of wash feet equal to one horse-power; a starching mangle, one horse-power; a drying and squeezing machine equal to one horse-power; and a calender from three to eight horse-power, according to its quality.

Flax Mills. Six stocks are considered to require the power necessary to turn a pair of corn millstones with shelling-stones, fans, sifters, and other attendant machinery; therefore each stock is equal to one horse. The bruising machine, consisting of three rollers, may be considered equal to one and a half stocks.

Spinning Mills. Coarse yarns require a greater proportionate power than fine; this is chiefly owing to the additional trouble necessary to prepare the coarser kinds for the spindle; the spindles and their machinery are also heavier.

Yarn is distinguished by its degrees of fineness, and known by the number of leas or cuts it yields to the pound: a bundle is twenty hanks; a hank is twelve leas or cuts, and a cut is 300 yards in length.

Tow is usually spun at from 2 to 5 leas to the pound, and in the dry way, including the carding and preparation, it requires a horse-power to 40 throstle spindles.

Coarse Yarn, from 13 to 18 leas to the pound, including the preparation, requires a horse-power to 80 spindles.

Yarns spun from 20 to 60 leas to the pound require nearly the same preparation and machinery, and a horse-power is equal to 120 spindles in the wet and warm way.

In Yarns spun from 60 to 100 leas to the pound, a horse-power will work 200 spindles, including all the preparation; but the spindles and attendant machinery will be lighter than in the other cases.

In Cotton Mills the throstle spindle is used for the coarser yarns, and for the finer kinds the mule spindle.

With Throstle Spindles few manufacturers spin a coarser kind than 10 leas to the pound, none higher than 30; taking 20 as a fair average, the horse-power would drive 180 spindles.

With Mule Spindles, at an average of 50 leas to the pound, a horse-power, including the preparations, will turn 500 spindles, and this is varied up to 1000 spindles to the horse-power; but in this latter case the cotton must be clean, of superior quality, and spun to the finer degrees. By inquiries based upon the foregoing, the number of horse-power may be obtained, and consequently the value of the water-power.

Paper Mills, saw mills and others containing machinery driven by water, may be all estimated, and their value determined by calculating in the same manner.

Before the valuator commences any survey, he must be provided with good maps, having a field scale, and proper measuring rods or tape for taking the dimensions of the buildings that are upon the estate.

Where the district is mountainous or hilly, it is also necessary that he should carefully examine the crops, and make due allowance for the difference of elevation, and where land lies in the interior of a mountain, or is surrounded by high land, some consideration should be allowed: land also which has a southern aspect is of more value than that which lies to the north, and Vitruvius explains to us why that species of fir known at Rome by the name of *supernas* is not so good as that which is called *infernas*, whose durability in buildings is so great; "the hither side of the Apennines towards Tuscany and Campania is in point of climate extremely mild, being continually warmed by the sun's rays; the further side, which lies towards the upper sea, is exposed to the north, and is inclosed by thick and gloomy shadow. The trees, therefore, which grow at that part being nourished by continual moisture, not only grow to a great size, but their fibres, being too much saturated with it, swell out considerably, and then are unfit for building: those which grow in sunny places are more solid, and, in consequence of the closeness of their pores, are exceedingly lasting. The infernas, as those firs are called which are brought from warm open parts, are preferable to the sort called supernas, which come from a closely and thick-wooded country."

CHAP. X.

VALUE OF ARTIFICERS' WORKS IN ENGINEERING.

THE exact valuation of the price of work being one of the most important elements in the execution of great enterprises, the basis upon which it should be founded, it is our first duty to consider.

The price of work depends upon several elements, which may be classed as follows: —

The prime cost of the materials:

The waste which occurs in converting them to use:

The manual labour:

The incidental expences, such as tools, machines, workshops, &c. &c.; and persons employed as clerks of the works, foreman, &c.:

The interest of money on capital, and the profit thereon.

The principal materials employed are stone, brick, lime, sand, and other substances which unite with lime; timber, iron, lead, copper, &c.

The price of these comprehend, first, that of the material itself, then its conversion and carriage. The only method of estimating its value is to acquire a correct knowledge of these three objects, and particularly the manual labour consumed in its conversion, which generally forms the chief item: usually the price current of the materials is the one acted upon; and these vary according to circumstances. The loss which materials suffer in their employments depends in part upon their quality, and on the workmen, as well as the care and diligence of those who direct them. The manual labour is not so difficult to ascertain.

The execution of work may be divided into three operations,—preparing the materials, their carriage, and fixing; each of these may be subdivided and separately calculated: among the tools employed, some are found by the workmen, and the wear and tear forms a portion of the labour; some of the machines used in large works are provided by the government, or the company that promotes them.

The expense of overlooking workmen consists in the payment of foremen and clerks, who do not labour, but keep the account of the various materials and time.

Gauthey in his valuable work, "Traité de la Construction des Ponts," has given us the following data upon which we may form our calculations, and it is to be regretted we have not had similar experiments made upon the labours of English workmen.

Ground Work: under this title is comprehended the digging and removal of earth, laying the turf, ballasting and dredging, &c. Excepting charges made for cutting turf, the only expense for these works is the labour; they are generally performed by a lower grade of workmen, and in companies. The price required is given in hours; the price of an hour depends upon the value of a day's work, and the number of hours or effective hours it contains, which is usually ten.

Excavating. The time employed in digging depends upon the nature of the soil; and the mean results, which serve as comparisons, are as follows: —

		Parts of an Hour.
Vegetable earth, per cube metre,	or 35·3 cubic feet English, or one and a third cube yards.	0·60
Loam, —		0·90
Clay, —		1·50
Stony earth —		2·00
Tufa, —		2·50

Removal of Earth comprises loading and unloading: when the barrows or carts cannot approach close to the workmen, it is necessary to throw the earth with a shovel, either horizontally or vertically on scaffolds raised 2 metres over each other.

For throwing a cube metre (or 1⅓ cube yards English) with a shovel:

	Parts of an Hour.
Vegetable earth, loam, or sand	0·65
Hard earth, clay, and tufa	0·75
Mud	0·80

When the removal takes place by barrows, it is executed by relays; if the ground is level, or slightly inclined, each relay is 30 metres in length, and 20 when the inclination is 1 in 12½.

For loading in barrows a cube metre, or 1⅓ cube yards English.	Vegetable earth, loam, and sand	0·60
	Clay, stony ground, and tufa	0·70
	Mud	0·75
For removal to a relay	Vegetable earth and loam	0·45
	Clay, stony earth, sand, mud	0·55

The specific gravity of vegetable earth and loam is 1·5, and each barrow contains 0·04 cube metres.

It is most advantageous to use carts when the distance is from 150 to 200 metres: when this distance is not very great, trucks drawn by men are preferred; some of a very ingenious construction, used at the bridge of Neuilly, contained 0·2 cube metres of loam, and were drawn by three men.

		Parts of an Hour.
A cube metre drawn by trucks	Vegetable earth, loam, and sand	0·63
	Clay, hard stony earth	0·73
	Mud	0·78

For the removal, each cube metre of earth is estimated in the following manner: supposing five trucks employed, drawn by three men, and three workmen employed to load,

		Parts of an Hour.
Time for loading a truck, containing 0·2 cube inches	Vegetable earth, loam, and sand	0·042
	Clay, hard stony earth, and tufa	0·049
	Mud	0·052
Time to go a distance of an hundred metres, and return, the ground being level, or nearly 110 yards English	Vegetable earth and loam	0·060
	Clay, stony earth, sand and mud	0·070
	Time of unloading	0·030

If the road is bad, or the rise and fall considerable, some additional allowance must be made. When carts drawn by horses are used, it is advantageous to have as many men to load as is practicable; our calculations suppose three employed for that purpose.

		Parts of an Hour.
To load a cube metre in a cart	Vegetable earth, loam, and sand	0·65
	Clay, stony earth, &c.	0·75
	Mud	0·80

The price of transport varies with the number of horses employed; during the time of loading the horse is unemployed, and this evil is increased in proportion to the size of the carts, and to the shortness of the distance; the carts should be made in proportion; and small ones used where the distance is not great. A cart with one horse should be employed where the distance does not exceed 313 metres; two horses where it does not 1104 metres; three horses to 2111 metres; and four horses to 3873.

Supposing each horse to draw half a cube metre of earth, the following estimate may be made: —

Time of loading a one-horse cart containing 0·5 metre	Vegetable earth, loam and sand	0·108	Hours for two one-horse carts, 300 metres distance. One cart from 300 to 1100 metres. Two-thirds of a cart of three horses from 1100 to 2000 metres. Half a cart of four horses, from 2000 to 4000 metres.
	Clay, stony earth, and tufa	0·123	
	Mud	0·133	
Ditto two-horse cart, containing a cube metre	Vegetable earth, loam, and sand	0·217	
	Clay, stony earth, and tufa	0·230	
	Mud	0·267	
Ditto three-horse cart, containing 1·5 cube metres	Vegetable earth, loam, and sand	0·325	
	Clay, stony earth, and tufa	0·353	
	Mud	0·400	
Ditto four horse cart, containing 2 cube metres	Vegetable earth, loam, and sand	0·434	
	Clay, stony earth, and tufa	0·460	
	Mud	0·484	
Time to go a distance of 100 metres, and to return	Vegetable earth and loam	0·060	
	Clay, stony earth, sand, and mud	0·070	
Time for unloading		0·050	

Earth is sometimes removed by boats, which generally contain from 40 to 50 cube metres: from what has been already stated, the loading and unloading may be easily calculated; as for the transport, it varies according to circumstances, and can only be estimated by the daily hire of the boat, and the number of journeys it can make. When the earth is shot from a cart or a truck it requires levelling, and a man is necessary for the purpose.

For levelling without throwing a cube metre	Vegetable earth, loam, &c.	0·15	Hour of a ground digger.
	Clay, stony earth, and tufa	0·25	
When more care is required, or a talus is to be dressed,			
Square metre of surface	Vegetable earth, loam, &c.	0·10	Hour of a ground digger.
	Clay, stony earth, and tufa	0·13	

Rammer.— Earth requires ramming, when used for cofferdams, or filling in behind walls, where it is necessary to produce immediate cohesion, that the thrust may be diminished; and also where it is intended to lay down a pavement. Vegetable earth; loam, and clay are alone susceptible of being rammed; the latter is not so well suited for this purpose. The operation is performed by laying the earth in beds of from 15 to 20 centimetres in thickness, and the ramming a cube metre of earth usually occupies 0·5 of an hour of the ground digger.

Some experiments have been made on the loss arising from the earth employed in cofferdams, which is caused by the joints of the sheet piles; the result is, that in those of from 3 to 4 metres in height, the volume of earth carried into the part below the water is one half more than the void filled in the cofferdam, or the loss is one-third of the original volume; above the level of the waters, the loss is only one-fourth of the same volume.

Laying down Turf, the thickness of which is usually 10 centimetres, comprises three operations; taking up, removing, and laying down. The men usually employed, being of a superior grade, have more wages than the groundmen: to cut and remove a sufficient quantity of turf for one square metre requires 0·5 of an hour of the workmen; the removal may be estimated according to what has preceded. Laying it down depends generally on skill, but on a mean it takes 0·8 of an hour for a square metre. The value of the turf is governed by various circumstances, which require to be added.

Dredging is either performed by machines or by hand: moving sand is the only material upon which any calculation with regard to price can be formed. To remove with hand drags a cube metre of moving sand, at a mean depth of 1·5 metre under water, requires ten hours for a workman. This valuation implies that the labour is performed by men skilled in this employ, who usually receive twice as much as an ordinary labourer. When the machine is used, the time necessary to drag a cube metre at the depth of two or three metres under water may be estimated at an hour of the machine worked by five men; an allowance for the use of the machine must be added.

Incidental charges for Grrundwork, &c. comprise superintendants, providing planks,

scaffolds, wheelbarrows, trucks, &c.; the other tools belong to the workmen; the carts are usually hired by the day, in the price of which the value is comprised. It has been found that these incidental expenses amount to about one-twentieth of the labour. Suppose a cube metre of loam dug, thrown out, removed in wheelbarrows to 150 metres distance, and rammed. Taking the price of the labourer per day at two francs, or 20 pence English,

Digging	0·90
Throwing out	0·65
Loading the barrow	0·60
Removal at five relays at 0·45 hour for each	2·25
Ramming	0·50
Time employed by the workman	4·90

	Francs.
4·90 hours of the workmen is worth at 0·20 franc	0·980
$\frac{1}{20}$ for the incidental expenses	0·049
$\frac{1}{10}$ for profit	0·103
Total	1·132

If the same quantity of earth be removed in carts, it will require levelling down after being shot; and supposing the value per day for a cart and one horse be nine francs, the detail will be as follows.

Digging	0·90	
Throwing out	0·65	
Loading the cart	0·65	
Levelling	0·15	
Ramming	0·50	
Time employed by the workmen	2·85	
2·85 hours of the workmen at 0·20 francs is worth		Francs. 0·570
Removing in the cart	0·108	
Time in going 150 metres at 0·06 of an hour for 100 metres	0·090	
Unloading	0·050	
Time employed by the carts	0·248	
0·248 hour of two carts with one horse, at 1·80 francs, is worth		0·446
Total		1·016
$\frac{1}{20}$ for incidental expenses		0·051
$\frac{1}{10}$ for profit		0·107
		1·174

Whence it appears that for this distance there is a saving of 4 centimes per cube metre by using barrows in preference to carts.

Fascine Work and Fencing.—The materials used are branches of trees, stakes, and gravel to fill the intervening spaces: the price of the branches is at per cube metre, and regulated by the price of timber: the fascines are usually 2·5 metres in length, and 30 centimetres in diameter: the stakes are 1·5 metres in length, and 5 centimetres in diameter; when hurdles are employed, they are made with the longest rods that can be obtained, but not more than from 2 or 3 centimetres diameter at the largest end; the distance between the stakes varies according to the strength required; it is usually about 50 centimetres. With regard to the quantity of material for the execution of these works, a fascine with its four stakes will require two cube metres of branches; there will be $1\frac{1}{3}$ fascines in the cube metre of each row, the thickness of which will be reduced, after placing and driving in the stakes, to 20 centimetres; it will then require $6\frac{2}{3}$ fascines for every cube metre of work performed: if hurdle rods are used across the fascines to tie them together, there will be 0·1 cube metre of branches for a square metre of each row, or 0·5 cube metre for a cube metre of work: if the spaces are filled with gravel, it will require about 0·1 cube metre for every cube metre of work. To make a fascine with its four stakes employs half an hour; for placing and driving them an hour, which

together, for a cube metre of work, occupies ten hours of labour; placing rods for hurdles on a square metre 0·65 hours, which amounts for a cube metre of work to 3·25 hours: the time necessary for spreading the sand is about 0·25 hours per square metre, which amounts to 0·75 hours for a cube metre of work. The workmen usually have higher wages than the labourer; and the incidental expenses to be added are one-twentieth.

Carpentry.—The labour of this work includes the setting out at large the price of the timber, &c., the carriages, sawing, framing, and taking it to pieces in the yard; removing it to its destination, and raising the same in its place. The following calculations suppose the use of oak timber; with regard to fir, birch, chesnut, and other qualities, it will be easy to form a judgment of the proportion according to which it will be necessary to reduce the quantity of labour, which depends on the hardness and specific gravity of the timber.

		Mean.	Hours of a Carpenter.
To make a mortise requires	at least - - 1·00	1·50	3·25
	at most - - 2·00		
To make a tenon	at least - - 1·25	1·75	
	at most - - 2·25		
Halving the ends of plates or other timbers - - -		1·00	1·00
For a square metre in joints at the ends of brestsummer, &c. -		-	10·50
which gives for one joint, supposing the piece to be 25 centimetres square, and at the joint 50 centimetres in length -		1·31	2·50
Supposing the piece 35 centimetres square, and at the joint 1 metre in length - - - - - -		3·68	
For common framing - - - - - -		-	5·00
dovetailing - - - - - -		-	6·00
boring a metre in length for bolts - - -		-	1·00
boring the timber when fixed - - - -		-	3·00
sawing a square metre of timber on tressels - -		-	1·40
sawing in the yard a square metre of the ends of timber -		-	5·00
cutting off the heads of piles with the hand-saw for a square metre		-	10·50
sawing a square metre of planking with ditto - -		-	12·50
lining out and squaring for use - - - -		-	1·50
To fix a kilogramme of iron when the iron is to be let in - -		-	0·20
drive in or pull out an iron pin - - - -		-	0·15

Carpenter's work may be divided into several kinds: as that for foundations or scaffolding, which do not require timber to be squared or prepared; it is equally useless to reduce it to one thickness, except where planks are required to unite in a very exact manner: the labour is reduced to framing done on the spot, and fixing.

Temporary bridges and centres to vaults require that the timbers should be prepared after a working drawing, and the framing put together in the yard, but not wrought on the face: with regard to the carpentry of timber bridges, it is done agreeably to a drawing; the framing prepared and put together in the yard, and the faces wrought.

There are also works executed after a drawing that do not require to be wrought entirely, as horizontal sleepers or joists and binding pieces, which are generally faced in the yard, cut to a length and fitted at the place, the price of which differs from that of the timber.

		Parts of an Hour.
Planking and Piling.		
Preparing a pile for scaffolding, forming the head, and fixing the shoe -		1·25
Letting in the shoe, weighing 5 kilogrammes at 0·20 hours for each - -		1·00
Do. for a pile used in foundations - - - - - -		2·50
Letting in the shoe, weighing 10 kilogrammes at 0·20 hours for each -		2·00
To sharpen and prepare a lineal metre of sheet-planking, and putting on the shoes if not let in - - - - - - -		0·20
If the joints are grooved and tongued - - - - - -		0·80
For fixing the sheet piles - - - - - -		0·20
which gives for a sheet pile, 5 metres long, if the joints are square, 5 metres at 0·20 hours for each - -	1·00	1·20
Put into the frame or placed - - - - -	0·20	
If the joints are grooved and tongued, 5 metres at 0·80 hours for each - - - - - - -	4·00	4·20
Put into the frame - - - - - -	0·20	
If the shoes of the weight of 5 kilogrammes are let in, we must add 5 kilogrammes at 0·20 hours for each - - - - - -		1·00

Scaffolding. — Labour for fixing the heads on the top of the piles, including the mortise and tenons: piles 22 centimetres in diameter are placed 3 metres apart; the heads are 22 centimetres square, formed of pieces 5 metres in length; hence the labour of each running metre will comprise for the construction as follows: —

		Hours of a Carpenter.
Sawing the third of a pile, forming a surface of 0·013 square metres, at the rate of 10·50 hours per square metre	0·14	1·35
A third of framing, mortised and tenoned at the rate of 2·25 hours for each	0·75	
A fifth of framing for the end, at the rate of 1·3 hour for each	0·26	
Placing and adjusting	0·20	
Which amounts per cube metre to		27·89

	Hours of a Labourer.
And for the removing, unframing, &c., for a running metre	0·04
	0·06
Which amounts per cube metre to, for a carpenter	0·83
Ditto for a labourer	1·24

Workmanship of a Cube Metre of capping placed on the heads of the piles, fixed by iron pins.

Supposing the dimensions of the timbers and their distances apart to be the same as before: the labour for the construction will comprise,

		Hours of a Carpenter.
Sawing the piles, as before	0·14	0·69
Piercing one third of a hole, allowing a length of 7 centimetres at an hour per metre	0·07	
Placing a third of a pin at 0·06 hours for each	0·02	
Framing at the ends, as above	0·26	
Placing and adjusting	0·20	
Which amounts at per cube metre to		14·25
And for the unframing, &c., and taking out the third of a pin at 0·06 hours	0·02	0·06
Removing, &c.	0·04	
Hours of a labourer		0·06
Which amounts for a carpenter per cube metre to		1·24
Ditto for a labourer ditto		1·24

Labour upon a Square Metre of Waling Pieces, which secure the piles in a longitudinal direction, the piles being at 3 metres apart as before, and the pieces 25 centimetres in width.

		Hours of a Carpenter.
The running metre contains a third of a pin at 0·06 hours for each	0·02	0·12
Raising and adjusting	0·10	
which amounts per square metre to		0·48
For the demolition a third of the pin pulled out at 0·06 hours for one	0·02	0·06
Removing and stowing away	0·04	
Hours for a labourer		0·06
which amounts for a square metre to		0·24
Hours of a labourer		0·24

Labour for a Square Metre of Planks placed on a scaffold to form a floor.

The construction consisting in the arrangement on the scaffold will employ	0·02
For a labourer	0·08

The removing may be considered at the same price.

Cofferdams. — Labour for a cube metre of waling pieces bolted to the piles; the timber being 16 centimetres square, and 5 metres in length, and the distance between the piles 1·3 metres; it will then require 39·06 running metres to form a cube metre; the running metre will contain,

		Hours of a Carpenter.
0·77 holes for bolts, 46 centimetres in length, giving 35 centimetres at the rate of 3 hours per metre	1·05	1·51
½ joint at the end, at 1·30 hours for each	0·26	
Putting it in its place	0·20	
which amounts per cube metre to		58·98

		Hours of a Carpenter.
Removing the bolts at 0·77 bolts at 0·6 hours for each	0·05	0·10
Taking down and putting away	0·05	
Do. for a labourer		0·10
Which amounts per cube metre for a carpenter to		3·91
Do. for a labourer		3·90

When the timbers are used again the labour will be the same.

Labour for a Cube Metre of Entretoise (or entertyes) bolted to the piles, the scantling being as the timbers above, and their length each four metres: the running metre will comprise,

		Hours of a Carpenter.
Half a hole of a bolt, 40 centimetres long, giving 20 centimetres, at 3 hours per metre	0·60	1·05
Half letting in at the meeting of the piles, at the rate 0·50 hour for each	0·25	
Putting it in place	0·20	
which amounts per cube metre to		41·10
For demolition, half a bolt to remove at 0·06 hour for each	0·03	0·08
Removing and putting away	0·05	
For a labourer		0·10
which amounts per cube metre to	3·12 for a carpenter.	
Do. do.	3·91 for a labourer.	

The labour is the same when the timber is employed again.

Labour for a Cube Metre of Entretoise nailed against the piles, supposing the length of each entretoise 2 metres, and its scantling from 10 to 15 centimetres: it will require 66·67 running metres to form one cube metre; and the running metre will comprise when constructed,

		Hours of a Carpenter.
Placing an iron pin	0·06	0·21
Fixing or putting in place	0·15	
which amounts per cube metre to		14·00
For demolition	0·06	0·11
Removing and putting away	0·05	
Do. for a labourer		0·10
which amounts per cube metre to	7·33 for a carpenter.	
Do. do.	6·67 for a labourer.	

Labour for a Cube Metre of Deals framed in panels to slide, supposing the cross pieces are 2 metres apart, and the deals 25 centimetres wide and 8 centimetres thick, it will require 12·5 square metres to form a cube metre.

The square metre contains, when constructed, as follows,—

		Hours of a Carpenter.
Placing 4 pins at 0·06 hour for each	0·24	1·04
Framing the deals	0·50	
Placing the sliding planks	0·30	
which amount at per cube metre to		13·13
Demolition	0·24	0·44
Removing, putting away, &c.	0·20	
For a labourer		0·60
Per cube metre	5·50 for a carpenter.	
Do. do.	7·50 for a labourer.	

If the sliding planks are used again without being demolished, the labour will be reduced to the mere placing.

Carpentry for Foundations.—Labour for a Cube Metre (or $\frac{1}{10}$ of a load of timber English nearly), of capping placed on piles, into which they are mortised and tenoned; the piles being distant 1·25 metres, and the cappings composed of timber 5 metres in length, 10 running metres being required to form a cube metre; the labour of which will comprise,

	Hours.	Hours of a Carpenter.
8 mortises and tenons, at 3·25 hours each	26·00	33·00
2 joints at the end, 2·50 hours each	5·00	
Placing and adjusting	2·00	

Labour for a Cube Metre of Sleepers tenoned and mortised to the heads of piles, and halved at the ends to the cappings; the piles being at the same distance, and the scantling of the timber as before, each sleeper being 5 metres long.

		Hours of a Carpenter.
8 mortices and tenons as above	26·00	49·00
4 halvings at 5 hours each	20·00	
Placing and adjusting	3·00	

Labour for a Cube Metre of binding Pieces, let into the piles, and bolted to them.

		Hours of a Carpenter.
8 notches or halvings at an hour each	8·00	27·00
8 holes for bolts, each 50 centimetres in length, giving 4 metres at the rate of 3 hours for piercing on the plane, and fixing the bolt	12·00	
2 joints at the end, 2·50 each	5·00	
Placing and adjustment	2·00	

Labour for a Cube Metre of Capping or Sleepers, fixed to the piles by iron pins.

		Hours of a Carpenter.
8 bolt-holes 30 centimetres in length, giving together 2·4 metres, at the rate of 1 hour each for piercing	2·40	5·60
8 iron pins, driven in at 0·15 hour for each	1·20	
Placing and adjustment	2·00	

For the Labour when the Sleepers are under Water.

		Hours of a Carpenter.
Piercing the holes	2·40	10·40
8 iron pins driven in, 0·50 hour each	4·00	
Placing and adjustment	4·00	

Labour for a Cube Metre of Platform, with deals or planks, the thickness of which are 10 centimetres, and their width 25 centimetres.

		Hours of a Carpenter.
8 metres of joints in length to prepare, forming 0·8 square metres, at the rate of 0·15 of an hour per square metre	1·20	1·20
Placing and adjusting a square metre of floor	0·90	
Which amounts per cube metre to		21·00

The Labour when the Deals are framed together, and afterwards sunk under water.

		Hours of a Carpenter.
Preparing the edges and adjusting the planks as before	2·10	3·10
Sinking and placing under water	1·00	
Which amounts per cube metre to		31·00
If the platforms are in compartments, add per square metre		0·15
And per metre cube		1·50

Labour on Timber in the Yard.—The first operation is tracing the form by applying the mould, and ascertaining the proper timbers for the purpose; so that none be selected that would occasion much waste; it is then sawn, and the face over which the saw has passed is considered perfect; hence, there is economy in the employment of large timbers: if the faces are dressed with the axe or the adze, and the deals are formed from large timbers, then

		Hours of a Carpenter.
To select a cube metre of timber apply it to the mould, and line it out, for the least	3·00	4·50
for the most	6·00	

As for the cutting, it must be estimated according to the nature of the works, they being too various to be analysed: some general results will enable a judgment to be formed, which may approximate near enough for practice.

For the labour employed in cutting a cube metre of timber for the principals of a bridge, the total length of which is 36 metres, the scantling 30 centimetres, which form a cube of 3·24 metres.

For cutting a Cube Metre of Timber at the Yard.—Timber not wrought when used for centres or temporary bridges.

			Hours of a Carpenter.
Above 25 centimetres scantling	at least	10·	15·
	at most	20·	
Less than 25 centimetres scantling	at least	20·	25·
	at most	30·	

Timber wrought all round for Bridges, Palisades, &c. &c.

		Carpenters.
Above 25 centimetres, at least	30	40
ditto at most	50	
Below, 25 centimetres square, at least	40	50
ditto at most	60	
Timber rebated, &c. &c. above 25 centimetres		60
ditto below ditto		70
Timber used for machines, as cranes, pile-engines, &c. &c.		90
ditto, as capstans, &c.		150

The timbers having been cut and framed, the holes for the bolts bored, the timbers are numbered, taken to pieces, and laid aside in the yard, to be removed to their destination.

		Hours of a Carpenter.
Per cube metre at least	1·00	1·50
ditto at most	2·00	

Labour of Cutting consists of

	Hours.
Four pieces of framing, mortised and tenoned at the extremities of the braces, at 3·25 hours for each	13·00
8 notches for the two courses of waling pieces, 1 hour each	8·00
1 notch for the small timbers on the piles	0·50
2 end joints for the beams or sleepers at 2·50 hours each	5·00
9 holes for bolts, 60 centimetres each, for uniting the upper timbers to the sleepers, and for the binding pieces, making 5·40 metres, at the rate of 1 hour per metre	5·40
For cutting the pieces to a length, 20 ends, each having 0·09 square metres, and together 1·80 square metres, at the rate of 5 hours per metre	9·00
43·20 square metres of surface of face, to wrought at 1·5 hour per metre	64·80
Total	105·70

By dividing 105·70 hours by 3·24 cube metres, we shall have for the labour upon each cube metre, 32·62 hours: it will be seen that this limit is placed between 30 and 50 hours, as previously given. If the timber was not wrought, the labour would only be 40·9, which divided by 3·24 cube metres, gives for each 12·62 hours, a number placed between 10 and 20, as already cited.

Raising or putting up Timbers already framed. — The expense varies according to the work: if the timbers are of small scantling, the pieces are numerous, and caution great for the removal; carpenters are alone employed. When they are less important, machines worked by labourers are employed; there is some difficulty in fixing a value for this kind of work.

For the raising a Cube Metre of Timber.

		Hours.
When small timbers are used, and carpenters employed to raise it by hand, above 25 centimetres square	20	25
below ditto	30	

When the timbers are of an ordinary scantling, portions being already framed, and put together, the labour being performed by carpenters.

Timber above 25 centimetres square	10	15
ditto below ditto	20	

		Hours.
For large pieces of carpentry, such as the principals used in centring, &c. &c. raised by machines worked by labourers	carpenter	5·0
Above 25 centimetres square	labourer	10·0

For the striking the centres of vaults, removing temporary bridges, taking framing to pieces, and placing them in boats, &c.

	Hours.
For each cube metre, for a carpenter	2·0
ditto for a labourer	4·0

Carpenter's Work for the upper Parts.—The planks laid on the centres for the construction of vaults do not require any preparation at the yard, and therefore must be put at a different price to that of the centres.

For the Labour of a Cube Metre of Planks, supposing the principals or ribs 2 inches distance, and the scantling 20 centimetres, we have 25 running inches for a cube metre.

	Hours.	
Piercing 13·5 holes in each, 20 centimetres long, making 2·70 metres at an hour per metre	2·70	7·01
13·5 pins driving in at 00·6 hour for each	0·81	
Putting in place	3·50	

Timber used for floors and other parts of wooden bridges require no other preparation at the yards than reducing them to their proper scantlings; they must be valued accordingly.

Labour on a Cube Metre of Joists, supposing the principals at 1·5 metres distant, the scantling from 25 to 30 centimetres square, which gives 13·6 running metres to a cube metre, and 5 metres of length for the pieces, two of which will form the width of the bridge, each running metre will comprise:

	Hours of a Carpenter.	
Two thirds of a notch at the meeting of the sleepers at the rate of 0·5 hour for each	0·33	2·78
Sawing the ends, having 0·15 metres square, at 5 hours per square metre	0·75	
½ of the joint at the other end, at 1·30 hour	0·26	
4 wrought faces, 1·10 square metre at 1 hour	1·10	
¾ small pins, driving at 0·06 hours	0·04	
Putting in place or fixing	0·30	
Which gives per cube metre		37·53

Laying the planks on the floors of wooden bridges may be valued in the same manner as in the platform for foundations.

Carriage of Timbers.—Large timbers are usually moved by means of a truck; smaller, and planks, &c. are loaded on carts, &c.: when the distance is trifling, they may with advantage be carried by hand: the price of this portion of labour is not subject to much variation. The proportion of price is always relative to the weight and size of the timbers moved:—

Per cube metre	For loading	0·20	Hours of a truck served by 10 labourers.
	Unloading	0·15	
	For going, &c., or returning, a distance of 100 metres	0·06	

Waste upon Timber depends on the nature of the work, and the arrangements made between the merchant and contractor. Supposing the timber to be squared, the loss is then divided into three portions: first, on the round timber, as it has been felled; second, when squared or dressed on four sides, and reduced to a more regular figure: third, when sawn into planks and deals.

Round timber is seldom employed except for piles. The loss which is sustained on it arises from the length being usually greater than required; something is cut from the extremities to form the head and point, and such timber loses three-fourths of its value. The waste may be estimated at one-tenth of the primitive volume.

The waste upon square timber depends on the nature of the works. It may be estimated at one-eighth, which is near enough for timber prepared on its four faces, and at a tenth for rough timbers of the primitive volume. If the works contain circular pieces it is rare to find timber crooked enough naturally; regard must then be had to the waste sustained, and a price put accordingly. The waste on sawn timber is about an eighth of the volume, when the joints are wrought, and at a tenth when laid rough.

Waste on Timbers in temporary Constructions.—The cost of scaffolding centres and temporary bridges may, with respect to labour, be estimated in the manner before described; the timber used is generally taken away by the contractor, and an allowance made to him for the use and waste of one half. The diminution of value which timber sustains in the above works arises from the change produced in the quality, and from the adaptation to particular purposes, such as injury from piercing holes, mortices, &c.

Suppose a scaffold pile, five metres in length, cost 75 francs, and as the timber of this pile cut into lengths of a metre is only fit for fire-wood, its value would not be more than 25 francs the cube metre, and diminishing the length of the pile from five metres to one, the price of the cube metre will diminish in proportion.

Estimating, as above, one tenth for the loss sustained in the pile for forming the head and point, which is abridging it one tenth of its length; reducing it from 5 metres to 4·5 metres, which is the quantity it would be taken at in the estimate. When used, the head

and point are injured, and before it can be used again as a pile, or converted to any other purpose, it must be reworked, and reduced to 4 metres in length. The length of the pile will then have diminished a quarter of the interval from 1 metre to 5 metres: the price of the cube metre of timber must then be diminished a quarter of the interval between 75 and 25 francs; that is to say, it will be reduced to 62·50; consequently, if the pile is 25 centimetres in diameter, it will be worth $4 \times 0{\cdot}48 = 0{\cdot}192$ cube metres, at 62·50 francs; that is to say, 12 francs: but, according to ordinary custom, the contractors will take it at $4{\cdot}50 \times 0{\cdot}048 = 0{\cdot}216$ cube metres at 37·50 francs, that is to say, for 8·10 francs.

A piece 30 centimetres square, employed as a binding piece to a centre, and in which notches 10 centimetres in depth have been cut, and at the extremities a joint 50 centimetres long, will have sustained a loss of one metre in length, which will reduce the price of a cube metre of such timber to 62·50 francs. The notches do not affect the value, because a cube metre of timber 30 by 20 centimetres square is not essentially worth less than a cube metre of timber 30 by 30: but the piece must be considered as having lost one-third of its thickness; thus it is not worth more than $4 \times 0{\cdot}030 \times 0{\cdot}20 = 0{\cdot}24$ cube metres at 62·50 francs; that is to say, 15 francs.

According to custom, in the first example the contractor would be a considerable gainer; in the second, he would neither gain nor lose. As in carpentry, there are few timbers which belong to the second example, but many of the first which are little injured, it follows that the contractor obtains an advantage, if care be taken that the pieces be as little notched as possible, and the binding pieces attached by bolts: hence it appears that if an account is not taken of the loss which each work sustains, and a general proportion adopted, the contractor should take the timber back at two-thirds; that is to say, allowing one-third for use and waste; nevertheless it must be observed, that it often happens that the timber remains a long time on hand before it can be again used: this requires consideration, and perhaps a further allowance to be made.

There are temporary works executed with timber that has been previously employed for the same purpose, as cofferdams: on examining, if it requires any change in construction, the extra labour must be taken and valued accordingly: as for the loss sustained by recutting the timber, the proportion is the same as has been already given, or at about a fourth of the primitive volume.

Incidental Expenses for Carpenter's Work are considerable, independent of the expenses of management, which comprise the payment of the foreman, who marks out the timber, regulates the employment of the men, and that of the clerk, who enters an account of the time and materials: besides these, there is the rent and expenses in the yard, the cost of sheds for laying out the moulds, the machines, as pile-engines, crabs, scaffold-poles, blocks, and pulleys, windlasses, trucks, &c.; keeping them in order, and above all, the cordage and ropes, which are a considerable item of expense; the tools also which are not provided by the workmen but found by the master, of which there are several. These incidental expenses may be estimated at one tenth of the value of labour.

For the price of a cube metre of timber used in the platform of a foundation, supposing it framed, and fixed under water; the price of the timber per cube metre delivered at the yard being 75 francs: the carpenter's day's work 3·5 francs, and the labourer's 2 francs. The platform, 10 centimetres in thickness, may be formed out of timbers 30 centimetres square, by putting two cuts into it, or of timber 20 centimetres square with one cut; consequently, in the first instance, there will be 6·667, in the second 5, and the mean 5·833 square metres of sawing for a cube metre of platform. The price of the cube metre will then be valued as follows: —

	Francs.	Francs.
A cube metre of timber furnished	75·00	
5·833 square metres of sawing at the rate of 1·4 hour of a carpenter, valued 0·49 franc per square metre	2·86	77·86
An eighth for loss		9·73
Carriage, distance 200 metres, 0·47 hours of a truck, worked by 10 labourers, worth 2 francs	0·94	
Labour for framing, sinking and adjustment under water, 31 hours of a carpenter at 0·35 francs	7·35	8·29
A tenth of the labour for incidental expenses		0·83
Total		96·71
A tenth for the contractor's profit		9·67
Total		106·38

For the principals of a centre used in a stone bridge, composed of two arches, which are separately centred, the dimensions being unequal, so that it would be required to recut

the timbers to adapt them for the second centre. The manner of establishing this price depends in some degree upon the arrangement made with the contractors. Supposing the contractors take the timber back at two-thirds its original value, and the volume is equal to that which has been used, the price of the cube metre of timber for the first centre will be —

	Hours.	Francs.
A cube metre of timber delivered		75·00
A tenth for waste		7·50
Labour at the yard, lining out and gauging	8·00	
Cutting and framing	15·00	
Taking to pieces, numbering, &c.	1·00	
Total	19·00	
	Francs.	
19 hours of a carpenter at 0·35 francs value	6·65	
Carriage	0·94	
Raising: 5 hours of a carpenter	1·75	
10 hours of a labourer at 0·2 francs	2·00	13·78
Striking the centre: 2 hours of a carpenter	0·70	
4 hours of a labourer at 0·2 franc	0·80	
Second crriage	0·94	
One tenth of labour for incidental expenses		1·38
Total		97·66
One tenth for profit		9·77
Total		107·43
Deduct two-thirds of the value of the timber		50·00
Remains		57·43

With regard to the second centre, admit that in reworking the timber, a loss of a fifteenth takes place, the price of the cube metre will be —

	Francs.
Loss or waste, one fifteenth on 75 francs	5·00
Labour (as above)	13·78
Incidental expenses	1·38
Total	20·16
Profit	2·02
Total	22·18

Suppose, after an exact account is taken of the loss timber is subject to in the forming of centres, it be ascertained that after the execution of the first centre it has lost two-fifths of the primitive value, and after that of the second a fifth of the second value, the price of the cube metre of timber of the first centre would be —

	Francs.
Loss on the value of the timber, two-fifths of 75	30·00
Labour, as before	13·78
Incidental expenses	1·38
Total	45·16
One-tenth profit	4·52
Total	49·68

And observing that when the timber has sustained a loss of 30 francs out of 75 francs, it is only worth 45, the price of the cube metre for the second centre will be —

	Francs.
Loss on the value, one-fifth of 45 francs	9·00
Labour, as before	13·78
Incidental expenses, ditto	1·38
Total	24·16
One tenth for profit	2·42
Total	26·58

Masonry, valuation of.—Mortar, cutting and laying the stone.

Forming the Mortar.—The proportion of the materials used depends on their quality, as does also the waste, and which experience can alone value: it must be first ascertained how much a given measure of well burnt quicklime will produce when slaked; observing that quicklime always suffers a loss of about a tenth, on account of the core, which arises often from not being properly burnt. Secondly, the proportion of slaked limes and sand, or other materials used instead. Thirdly, the relation of the volume of the mixture after trituration, with the volume of the materials mixed. As to the labour, the slaking of the lime depends on the quantity as well as distance from whence the water is brought; it may be valued in general at eight hours of a labourer for every cube metre of quicklime; if the water is laid on, five hours of a labourer is sufficient.

Making the mortar requires care, and an account must be taken of the time employed for its due mixture; it may be considered that from 12 to 20 hours of a labourer is required for a cube metre. The waste in mortar may be computed at one-twentieth of its volume.

Rubble Work or Moëllon comprises the carriage of the stone from the yard where it is measured to the spot where it is to be used, and its adaptation, whether rough, piquet or hammer-dressed, in mass or faced, in walls or vaults. The removal is performed by barrows when the distance is not considerable.

	Hour of a Labourer.
Loading the barrows, per cube metre	0·8
Removal with one relay of from 20 to 30 metres, the specific gravity of the stone being 2	0·6

When the distance is greater, carts are employed, containing 0·21 cube metres, which are drawn by four men.

To load a cart containing a cube metre of moëllon 0·83 hours of a labourer.

		Hours of 4·767 carts, drawn each by four men.
The time employed for each cube metre of moellon.	Loading the carts containing 0·21 cube metres, three labourers to load	0·058
	100 metres going and returning	0·060
	Unloading	0·030

When the distance is considerable, the removal of the moellon is performed in carts drawn by horses: it will be easy to estimate it upon that of the removal of earth, reckoning 0·85 hours of a labourer for loading a cube metre in the carts, and observing that each horse which draws half a cube metre of earth weighing 1500 kilogrammes, can only draw

$$\frac{1{\cdot}5}{2}\ 0{\cdot}5 = 0{\cdot}375 \text{ cube metres of moellon.}$$

A man with a barrow, working ten hours, will remove $\frac{10}{06} = 16{\cdot}7$ cube metres of stone to a distance of 30 metres of level ground, or 20 metres when inclined. The specific gravity of stone being 2, the daily effective labour will be equal to $16{\cdot}7 \times 2 \times 30 = 1000$ kilogrammes moved 1000 metres on horizontal ground, and $16{\cdot}7 \times 2 \times 20 = 668$ kilogrammes moved 1000 metres on inclined ground.

For the removal by carts, a man in 10 hours would remove $\frac{10 \times 021}{0{\cdot}148 \times 4} = 3{\cdot}547$ cube metres of moëllon, 100 metres distance.

The daily effective labour then would be $3{\cdot}547 \times 2 \times 100 = 709$ kilogrammes carried 1000 metres: with respect to water carriage the value of transport depends upon various circumstances.

The labour required to execute a cube metre of moellon, including the labourers assisting the mason, as well as those making the scaffold:—

		Hours of a Labourer.
Per cube metre	Measuring the stone	0·70
	Throwing the stone and watering, without adjusting	0·80
	Ditto with adjustment	1·00

		Hours of a Mason and his Labourer.
Per cube metre	Masses placed dry by hand	4·00
	Masses placed rough	4·50
	Masses for walls requiring scaffolds	6·50

For placing a Square Metre:—

	Hours of a Mason.
Facing a wall of moellon laid dry	0·50
the same rough in mortar for walls	1·00
in vaults	1·50
hammer dressed, joints in mortar	9·00
vaults and circular on plan	10·00
the moellon cut for straight walls	11·00
vaults and circular parts	12·00

	Mason and Labourer.
To repoint the joints carefully with mortar or cement, without scaffolding	1·00
With scaffolding	1·25

The quantity of mortar used bears a proportion of about $\frac{1}{5}$ or at the most $\frac{2}{5}$ of the volume of the masonry: as the mortar only fills the voids left by the stones, it does not augment the volume; the mortar or cement used for pointing may be estimated at from 0·10 to 0·02 cube metres, per square metre of facing.

Brickwork.—The carriage of bricks may be estimated in the same way as moellon: the work requires more attention, and the labour is dearer.

It requires for a Cube Metre,

	Hours of a Bricklayer and Labourer.
For rough brickwork	5·00
For ditto, requiring scaffold	7·00

For the laying of faced Work, per Square Metre,

	Bricklayer's Hours.
Rough brick, joints struck, without adjustment, mortar, lime, and sand	1·20
Vaults, &c.	1·80

	Bricklayer and Labourer.
Per square metre, pointing without scaffolding	1·25
Per square metre, pointing with scaffolding	1·50

Bricks are usually sold by the thousand; the loss which they sustain in carriage is about $\frac{1}{25}$.

The quantity of mortar used varies in different works.

Works in rough Stone.—Stones larger than rubble or moellon are used for filling in, where rivers are rapid; they are also used to advantage in the lower beds of piers executed in moellon, and placed dry; above all, in forming the foundations of walls, where a timber platform is not considered necessary: when these stones are used rough, and placed without arrangement, the price is that of moellon, or a little more; when the faces are dressed, and each stone placed on wedges, the facing being plummed, the price approaches that of worked stone.

With regard to carriage, if the stones are too large for a cart, waggons for the purpose are appointed, and the charge for transport depends upon the dimensions. The waste varies between $\frac{1}{10}$ and $\frac{1}{8}$ of the primitive volume, and the quantity of mortar between $\frac{1}{20}$ and $\frac{1}{10}$.

Stone squared, and laid in Courses.—The first operation is cutting the stone, paying great attention to the joints and beds, which is oftentimes neglected, and that of the facings seen: the time required depends upon the nature and properties of the stone. The principal object is to face the stone, and the time necessary to execute a square metre being known, it may be used as a unit in the value of other work.

For squaring a Metre of upright facing,

	Hours of a Stone-cutter.
Of granite	28·00
Calcareous stone, hard	9·00
do. of another quality, soft	3·50

The granite and soft calcareous stone are the extremes of hardness and softness of stone employed in hydraulic constructions.

These valuations suppose the faces only rusticated, that is to say, raised or worked with chisel, and dressed with the point and the hammer (matting hammer) if it be axed or cut with the hammer on one side, and toothed on the other, then smoothed with the rip (a scratching tool) and mallet, we must add another three-fourths. The time necessary for cutting straight facings being known, the labour of curved facing may be estimated thus:

$$T' = \left(1 + \frac{m}{r}\, T\right): \begin{cases} T = \text{the time of cutting the face straight.} \\ T' = \text{the time of cutting a curved face.} \\ r = \text{the radius of curve of the surface of this facing.} \\ m = 0{\cdot}75. \end{cases}$$

Then the price of the curved facing will require the time necessary to reduce the stone to a plane face and a curved one. But if the reducing has for its object the execution of some parts in projection, as obtuse angles or retreats, it cannot be valued as if cutting a face; but an allowance of ten times the labour is required for mere plain work: after cutting the face, the beds and joints require the next consideration: both are valued at the same price, which is an erroneous system; the joints requiring much more reducing than the beds.

For cutting the joints	-	0·8	of the time necessary for
the beds	-	0·3	cutting the face.

Cutting mouldings for cornices is valued thus, a price for reducing the stone, and afterwards according to the girth of the mouldings, as moulded work: other expenses are incurred in cutting stone besides the labour, as tools and oil, &c.; for cutting granite, ten points are allowed for every square metre for the calcareous stones: this expense is trifling.

Stone suffers a waste, which varies from a tenth to a fourth. The carriage is performed by a truck, or low waggon, drawn either by men or horses.

Supposing the specific gravity of stone to be 2, a man can draw 0·055 cube metres, and six men are required to load and unload the blocks of stone; these six men will be sufficient for the service of the truck, when the volume of the stone does not exceed 0·38 cube metres; if the stones are heavier, a greater number of labourers must be employed, who will lose their time after loading, unloading, and during their return; and as it costs more to move a truck with men than with horses, there is a point where, relative to the weight, it becomes preferable to use the latter. The volume of stone that may be drawn by a horse being 0·4 cube metres, it is easy to determine the size of the stones which require one or more horses, and

When the stone is between 0·60 and 0·80 cube metres	1 horse
0·89 and 1·18	2 do.
1·29 and 1·58	3 do.
1·69 and 1·98	4 do.

Upon this basis the charge for transport may be easily obtained, when the time of loading and unloading is also known, which is in proportion to the dimensions of the stone; an hour is required for a block for every cube metre; and the time necessary for going and returning are 100 metres, 0·6 hour.

When the stone arrives, the masons receive it, and sometimes it is requisite to move it by machines when a block is 0·75 metres cube, and it is required to be raised 8 metres; for attaching and detaching the tackle, 0·50 hours is allowed for two men and six boys.

For mounting to 8 metres at the rate of 0·1 hour per metre, 0·80; the same number of men and boys being employed. To bed the stone requires a mason, two assistants, and a labourer: when great rapidity is necessary, there are in addition two others to lay the cement, and an additional labourer.

For a cube metre of stone.	for the placing -	3·00	hours of a mason, 2 assistants, and a labourer.
	for the grouting -	2·00	

It is not necessary to add anything for the construction of vaults; the experiments made at the bridge of Nemours indicated that placing the voussoirs is less costly than that of the courses of the facings of walls; bedding the cube metre of stone at this bridge required for the piers 2·94, for the abutments 3·, and for the vaults 2·67 hours. The quantity of mortar required varies from a tenth to a twentieth of the volume of the masonry.

After the work is done, the stone requires re-dressing and pointing, which ordinarily amounts to about a twentieth of the primitive cutting; a running metre of joint occupies half an hour for a mason and labourer; the mortar used in the joints may be estimated at 0·001 cube metre.

Beton.—The preparation of various species, and of mortar used for composing the backs of vaults, may be estimated in the same way as moellon: with regard to beton, some allowance must be made when it is thrown from a height into the water; the labour is about the same as that for throwing earth with a shovel, or stones for foundations: where it is thrown into an inclosure with ease, an allowance must be made.

The covering of the backs of arches of bridges is so important for their preservation, that great care should be used. The labour to spread and level each layer should be valued for a cube metre at 4·5 hours of a mason, served by a labourer; and that of the beating at 1·5 hours of a labourer for every square metre of each of the layers beaten. The labour

for stucco, with which the facings in moellon are sometimes covered, is nearly the same as that of the pointing, the quantity of mortar being a little greater.

Incidental Expenses on Mason's Work consist in the maintenance of the machines used, timber and cordage for scaffolding, saws, sieves, roller, pincers, &c. The tools for cutting and laying the stones belong to the workmen: these incidental expenses amount to about one tenth of the labour.

Iron-work. — A smith usually works, winter and summer, twelve hours per day.

		Smith and his Assistant.
There is employed in the manufacture of a kilogramme of iron	For iron of large dimensions, as ties, &c.	0·10
	For cramps, &c.	0·40
	For pins, bolts, &c.	0·70

		Of the Primitive Weight.
Loss of iron may be valued at	For the first	0·03
	For the second	0·08
	For the third	0·10

		Cube Metres.
The volume of coal used for a kilogramme.	For the first	0·0001
	For the second	0·0006
	For the third	0·0010

Making the screw ends of bolts, according to their size, requires from 0·2 to 0·5 hours of a smith for the screw and its nutt: with regard to the placing or fixing ironwork, if it is done by the smith it may be valued at

		Hours of a Smith and his Help.
For a kilogramme of iron, including carriage	For the first class	0·04
	For the second	0·20
	For the third	0·40

As for running in with lead, &c. it is difficult to fix a price.

Incidental Expenses. — These are considerable: as all the tools are furnished by the contractor, they are generally put at one-fifth in ordinary buildings, but in bridges, &c. one-seventh is sufficient.

Painter's Work. — The colours usually employed are lamp-black, red and yellow ochre, linseed oil, turpentine, &c.: to cause them to dry quickly, litharge is added. The labour of the painter is employed to grind the colours and to lay them on.

		Hours of a Grinder.
For grinding a kilogramme of colour in oil	Red ochre	8·5
	Yellow ochre	6·5
	Lamp-black	8·5

The quantity of oil necessary for the above: —

		Kilogrammes of Oil.
For grinding a kilogramme	Red ochre	0·5
	Yellow ochre	0·5
	Lamp-black	0·8

The colours being ground, they must then be mixed with a sufficient quantity of oil to be in a condition to lay on.

		Kilogrammes of Oil.
To mix a kilogramme	Red ochre	0·62
	Yellow ochre	0·73
	Lamp-black	1·17

If turpentine is used for the above quantity, half the oil is employed with the same quantity of turpentine: sometimes one-eighth of litharge is added.

To paint a square metre two coats requires

	Kilogrammes of prepared Colour.
Red or yellow on timber	0·12
Olive colours	0·11
Black	0·08

The waste may be valued at a twentieth of the original weight.

Time necessary to mix and apply the colours —

		Hours of a Painter.
For a square metre	Without scaffolding	0·2
	With a flying scaffolding	0·5

To find the value of painting a square metre, the price of the colour ground, and the labour of painting:

	Francs.
One coat—0·11 kilogrammes of colour at 2·17 francs	0·239
One-twentieth of loss, 2·51	0·012
0·2 hours of a painter at 0·45 francs	0·090
One-seventh of labour for incidental expenses	0·013
One-tenth for profit, 1·03	0·035
Total	0·389

Pitching, applied to new timber or to that already pitched: in the latter case some allowance must be made for scraping off.

		Hours of a Man.
Per square metre comprising heating the pitch.	Clearing off	0·01
	Pitching without scaffolding	0·07
	Pitching with scaffolding	0·10

Upon a square metre about 0·0003 cube metre of pitch is required for new timber; 0·0002 when it has already been pitched.

The incidental expenses may be valued at one-seventh of the labour.

Tables of various Measures in English Feet and Decimals, from Folkes, Raper, Shuckburgh, Vega, Hutton, Ozama, Cavallo, Young, &c.

Ancient Measures.

	Eng. ft.
Arabian foot	1·095
Babylonian foot	1·144 / 1·135
Drusian foot	1·090
Egyptian foot	1·421
stadium	730·8
Greek foot	1·009 / 1·006 / 1·007
Phyleterian foot	1·167
Hebrew foot	1·212
common cubit	1·817
sacred cubit	2·002
great cubit = 6 common	
Macedonian foot	1·160
Natural foot	·814
Ptolemaic = Greek foot	
Roman foot	·970 / ·967 / ·966
before Titus	·970
after Titus	·965 / ·9672 / ·9681 / ·9696
Roman mile of Pliny	4840·5
Strabo	4903·
Sicilian foot of Archimedes	·730

Modern Measures.

	Eng. ft.
Attdorf foot	·775
Amsterdam foot	·927 / ·930 / ·931
Amsterdam ell	2·233
Ancona foot	1·282
Antwerp foot	·940
Aquileia foot	1·128
Arles foot	·888
Augsburg foot	·972
Austria, *see* Vienna.	
Avignon, *see* Arles.	
Barcelona foot	·992
Basel foot	·944
Bavarian foot	·968
Bergamo foot	1·431
Berlin foot	·992
Bern foot	·962
Besançon foot	1·015
Bologna foot	1·244 / 1·250
Bourg en Bresse foot	1·030
Brabant ell in Germany	2·268
Bremen foot	·955
Brescia foot	1·560
braccio	2·092
Breslau foot	1·125
Bruges foot	·749
Brussels foot	·902 / ·954
greater ell	2·278
lesser ell	2·245
Castilian vara	2·746
Chamberry foot	1·107
China mathematical foot	1·127
imperial foot	1·051 / 1·050
li	·606
Cologne foot	·903
Constantinople foot	2·195 / 1·165
Copenhagen foot (Denmark)	1·049
Cracau foot	1·169
greater ell	2·024
lesser ell	1·855
Dantzig foot	·923
Dauphiné foot	1·119
Delft foot	·547
Denmark old foot	1·047
new foot	1·036
Dijon foot	1·030

	Eng. ft.
Dortrecht foot	·771
Dresden foot	·929
ell 2 feet	1·857
Edinburgh, *see* Scotland.	
Ferrara foot	1·317
Florence foot	·995
braccio	1·900 / 1·910
barilo of wine weighs 140 Florence pounds = 20 fiaschi.	
cogno = 10 barili.	
rubbio of wheat 640 Rom. lbs.	
Franche Comté foot	1·172
Genoa palm	·812 / ·800 / ·817
canna	7·300
Geneva foot	1·919
German mile = $\frac{1}{15}$ degree.	
Grenoble, *see* Dauphiné.	
Halle foot	·977
Hamburgh foot	·933
Heidelberg foot	·903
Inspruck foot	1·101
Ireland perch 7 yards.	
acre 7840 sq. yds.	Eng.
Italy, old common mile	5299·
Leghorn foot	·992
Leipzig foot	1·034
ell	1·833
Leyden foot	1·023
Liege foot	·944
Lisbon foot	·952
Lombardy mile $\frac{1}{87}$ degree.	
Lucca braccio	1·958
Lyons, *see* Dauphiné.	
Madrid foot	·915 / ·918
vara	3·263 / 3·285
Maestricht foot	·916
Malta palm	·915
Mantua brasso	1·521
braccio	2·092
Marseilles foot	·814
Mechlin foot	·753
Mentz foot	·988
Milan decimal foot	·855
Aliprand foot	1·426
braccio	1·725
Modena foot	2·081
Monaco foot	·771
Montpellier pan	·777
Moravian foot	·971
ell	2·594
Moscow foot	·928
Munich foot	·947
Naples palm	·861 / ·859
canna	6·908
mile = $\frac{1}{35}$ degree or $\frac{1}{60}$.	
barilo of wine = 60 carafe.	
carafa = $\frac{2}{3}$ Parisian pint.	
batto = 12 barili.	

	Eng. ft.
Naples carro = 2 botti	
tumulo of wheat 3 cubic palms or 40 rotoli.	
Nuremberg town foot	·996 / ·997
country foot	·907
artillery foot	·961
ell	2·166
Padua foot	1·406
Palermo foot	·747
Paris old foot	1·066 / 1·06578
	Eng. in.
point	·0148
line	·0888
ell 44 French inches.	
sonde 5 French feet.	
toise 6 French feet	76·736
perch 18 French feet.	
perch royale 22 Fr. feet.	
league 2282 toises = $\frac{1}{25}$ deg.	
square foot or inch	1·1358
cubic foot or inch	1·21061
arpent, 100 square perches, about $\frac{5}{6}$ Eng. acre.	
measure royale about $\frac{5}{4}$.	
	Eng. c. in.
pint 48 cubic inches	58·11
litron	74·375
boisseau 1190 = 16 litrons.	
minat = 2 boisseau, nearly a bushel Eng., 2380 cubic in. English.	
mine = 2 minats, 4760 cubic in. English.	
septier = 2 mines, 9520 cubic in. English.	
muids = 12 septiers.	
ton of shipping 42 cubic ft.	
	Eng. ft.
metre 3·07844 Fr. ft.	3·281
	Eng. in.
millimetre	·03937
centimetre	·39371
decimetre	3·93708
metre	39·37079
decametre	393·70790
hecatometre	3937·07900
kilometre	39370·79000
myriametre	393707·90000

8 kilometres are nearly 5 miles.
1 inch is ·0254 metre.
1000 feet are nearly 305 metres.

	Eng. in.
1 centimetre is	·39371
2 ——	·78742
3 ——	1·18113
4 ——	1·57483
5 ——	1·96854
6 ——	2·36225
7 ——	2·75596
8 ——	3·14966
9 ——	3·54337
10 ——	3·93708

1 square centimetre = ·155006 square inches.

Paris, 1 are or square decametre = 3·95 English perches.
1 hectare = 2 acres, 1 r. 35·4 perches English.

	Eng. cubic in.
millilitre	·06103
centilitre	·61028
decilitre	6·10279
litre or cubic decimetre	61·02791
decalitre	610·27900
hectolitre	6102·79000
kilolitre	61027·90000
myrialitre	610279·00000

1 litre is nearly 2⅛ wine pints.
1 kilolitre, 1 tun 12¾ wine gals.
1 decistre of firewood 3·5317 cubic feet English.
1 stere or cubic metre 35·3171.

	Eng. ft.
Parma foot	1·869
braccio	2·242
Pavia foot	1·540

Piedmont old mile = 1½ mile Eng.
Placentia, *see* Parma.

Prague foot	·987 / ·972
ell	1·948

Provence, *see* Marseilles.

Rhinland foot	1·030

Riga, *see* Hamburg.

Rome palm	·733
foot	·966
oncia $\frac{1}{12}$ foot	·0805
deto $\frac{1}{18}$ foot	·0604
palmo	·2515
palmo di architettura	·7325
canna di architettura	7·325
staiolo	4·212
braccio dei mercanti	2·7876 / 2·856
canna dei mercanti	6·5365
braccio dei tessitor	2·0868
braccio di architettura	2·561
mile $\frac{1}{25}$ degree.	

Rouen, *see* Paris.

Russian arschin	2·3333 / 2·3625
vershock, $\frac{1}{16}$ arschin	·1458
werst	3508·

Savoy, *see* Chambery.

Scotland, ell 37 Scotch inches (37·2 Eng. inches)	3·100
fall, 6 ells (223·2 Eng. in.)	18·600
furlong	744·
mile	5952·

	Eng. in
link	8·93
chain	892·8
rood	1339·2

acre 55353·6 sq. ft. = 1·27 of English acre.

	cubic in.
gill	6·462
mutchkin	25·85
choppin	51·7
pint	103·4
quart	206·8
Scotland, gallon	827·23
hogshead (16 gallons)	13235·7
gallon of the Union barrel	799·
Lippie or feed English barrel	200·345
pint jug of Stirling	103·72
Aberdeen	105·30
firlot of Linlithgow (31 pints)	3205·5
firlot for wheat	2150· / 2197·3

firlot of Edinburgh 1½ per cent more.

Seville, *see* Barcelona.

	Eng. ft.
vara	2·760
Sienna foot	1·239

Spain league = 4 miles English.

Stettin foot	1·224
Stockholm foot	1·073
Strasburg town foot	·956
country foot	·969

Toledo, *see* Madrid.

Trent foot	1·201
Trieste ell for woollens	2·220
for silk	2·107
Turin foot	1·676 / 1·681
ras	1·958
trabuco	10·085
Tuscany mile	5329·

see Florence.

Tyrol foot	1·096
ell	2·639
Valladolid foot	·908
Venice foot	1·137 / 1·140 / 1·167
braccio of silk	2·108
ell	2·089
braccio of cloth	2·250

mile $\frac{1}{68}$ or $\frac{1}{67}$ of a degree.
moggio of wheat weighs 528 Venice pounds.

Verona foot	1·117
Vicenza foot	1·136
Vienna foot	1·037
ell	2·557
post mile	24888·

yoke of land 1600 square fathoms.
metz or bushel 1·9471 cube feet of Vienna.
eimer = 40 kannen = 1·792 cube ft. of Vienna.
fass = 10 eimer.

Vienne Dauphiné	1·058
Ulm foot	·826
Urbino foot	1·162
Utrecht foot	·741
Warsaw foot	1·169

Wesel, *see* Dordrecht.

Zurich foot	·979 / ·984

Table of various Weights.

Ancient Weights.

	Eng. grs.
Attic obolus	8·2 / 9·1
drachma	51·9 / 54·6
lesser mina	3892·
greater mina	5189· / 5464·
medical mina	6994·
talent = 60 mina = ½ cwt	
old Greek drachm	146·5 / 62·5
old Greek mina	6425·
Egyptian mina	8326·
Ptolemaic mina of Cleopatra	8958·
Alexandrian mina of Dioscorides	9992·
Roman denarius = ⅛ oz.	51·9
= ⅐ oz.	62·5
ounce	415·1
= avoirdupois oz.	437·2
pound of 10 oz.	4151·
pound of 12 oz.	4981· / 5246·

Modern Weights.

Pounds.	Eng. grs.
Aleppo rotolo	30985·
Alexandria	6159·
Alicant	6909·
Amsterdam	7461·
Amsterdam commercial	7636·
stone 16 pounds.	
ounce $\frac{1}{16}$ pound.	
drop $\frac{1}{10}$ ounce.	
Antwerp	7048·
Avignon	6217·
Basel	7713·
Bayonne	7461·
Bergamo	4664· / 11660·
Bergen	7833·
Berlin	7232·
Bern	6722·
Bilboa, *see* Bayonne.	
Bois le Duc	7105·
Bordeaux, *see* Bayonne.	
Bourg	7074·
Brabant	7249·
Brescia	4497·
Brussels heavy pound	7602·
light pound	7201·
Cadiz	7038·
China kin	9223· / 5802·
leang $\frac{1}{10}$ kin.	
tsien $\frac{1}{10}$ leang.	
Cologne	7220· / 7218·
Constantinople	7578·
Copenhagen	6941·
Cracau commercial	6252·
mint mark	3071·
Damascus	25613·
Dantzig	6574·

Pounds.	Eng. grs.
Dresden	7210·
Dublin	7774·
Florence	5287·
ounce = $\frac{1}{12}$ pound	440·6
France, *see* Paris.	
Geneva	8407·
Genoa = 12 ounces	4426· / 6638·
rotolo = 18 ounces.	
rubo = 25 pounds.	
cantaro = 6 rubi.	
peso = 5 cantari.	
Germany apothecaries	5523·
Hamburg	7315·
Ireland, *see* Dublin.	
Konisberg	5968·
Leghorn	5146·
Leyden	7038·
Liege	7089·
Lille	6544·
Lisbon	7005·
London avoirdupois	7000·
troy	5760·
Lucca	5273·
Lyon silk	6946·
town weight	6432·
Madrid	6544·
Marseilles	6041·
Melun	4441·
Messina	4844·
Montpellier	6218·
Namur	7174·
Nancy	7038·
Naples = 12 oncie	4952·
rotolo = 33⅓ o.	
staro = 10⅓ r.	
cantaro = 100 r.	
oncia = 30 trapezi.	
trapeso = 20 mini.	
Nuremberg	7871·
Paris (1·08 lb.)	7561·
marc = ½ pound.	
ounce = ⅛ marc.	
gron = ⅛ ounce.	
denier = ⅓ gros.	

	Eng. grs.
grain = $\frac{1}{24}$ denier	·8203
milligramme	·0154
centigramme	·1543
decigramme	1·5433
gramme	15·4330
decagramme	154·3300
hecatogramme	1543·3000
kilogramme, 2 lb. 3⅓ oz. avoirdupois	15433·0000
myriogramme	154330·0000
quintal = 10 myriogrammes.	
millier = 1000 chiliogrammes = 1 ton.	
sous, 5 grammes of copper.	
franc, 5 grammes of silver with $\frac{1}{10}$ of copper.	
Prague commercial pound	7947·
Revel	6574·

	Eng. grs.
Riga	6149·
Rome = 12 oncie	5257·
oncia = 8 dramme.	
dramma = 3 scrupoli.	
scrupolo = 12 oboli.	
obolo = 4 silique.	
siliqua = 12 grani.	
Rouen	7772·
Saragossa	4707·
Scotland troy pound Dutch	7621·8
iron pound, ⅘ troy	9527·25
Seville, *see* Cadiz.	
Smyrna, commercial pound	6544·
Stettin	6782·
Stockholm	9211·
Strasburg	7277·
Toulouse	6323·
Turin	4940·
Tunis	7140·
Tyrol	8693·
Venice	4215· / 6827· / 5374·
Verona	4676·
Vicenza	6879·
Vienna, commercial	8648·
apothecaries 420· Fr. gram.	
mint mark 280·64 Fr. gram.	
carat of the jewellers ·206085 Fr. gram.	

Apothecaries' Grains of different Countries from Vega.	
Austria	1·125
Bern	·956
France	·981
Genoa	·850
Germany	·958 / ·959
Hanover	·978
Holland	·989
Naples	·860
Piedmont	·824
Portugal	·864
Rome	·909
Spain	·925
Sweden	·955
Venice	·809

CHAP. XI.

MECHANICS.

As quantity, space, and number are understood and comprised in mathematics, so their application more immediately belongs to mechanics and hydrodynamics: but before we enter into the principles which affect falling bodies or those which belong to bodies revolving round a centre, or the general laws of machinery, it is necessary to describe the physical properties, or those external signs by which matter is recognised either in its solid, liquid, or aeriform condition.

Extension is that property by which a body occupies a certain space: by it is understood its volume or figure; the measure of the extension and compression of uniform elastic bodies is proportionable to the force which produces it; when, for instance, a weight is suspended to a bar of iron, causing it to be prolonged, if twice that weight be added, the effect will be doubled, and it was proved by Dr. Hooke, that the application of these weights in a contrary direction would shorten the bar in the same proportion. Dr. Young has suggested that the elasticity of a substance may be expressed by the weight of a certain column of the same substance, which he calls the modulus of elasticity, and of which the weight is such that any addition to it would increase it in the same proportion as the weight added would shorten by its pressure a portion of the substance of equal diameter.

Impenetrability implies that a body is so compact in its structure as not to allow another to pass through it.

Matter may be understood to comprehend whatever occupies space, and possesses extension and impenetrability; such are all bodies that have magnitude, or that comprise length, breadth, and thickness, as well as those which have surfaces only.

Porosity is that property which indicates that there are interstitial spaces lying between the particles or molecules of matter, usually called pores.

Mass and Density are estimated according to their various properties of porosity; the mass comprises the material particles, and the greater their quantity the less porous the body or substance will be: density, on the other hand, expresses the relation of the masses when the volumes are equal; or, of any two bodies, that is the most dense which with equal bulk contains the greater mass.

Compressibility implies that the body may be diminished by pressure without the mass being lessened by forcing the particles which compose it closer together and diminishing the size of the pores.

Dilatability is the reverse of the former: the pores are increased by throwing the particles farther from each other, which is affected by heat, or raising the temperature of a body.

Elasticity is the power of a body to resume its original state, as in the case of a spring, or when compression has taken place.

Motion is a successive and continuous changing of place, and may be accelerated, retarded, or made either absolute or relative.

Repose is the state of matter when in perfect rest.

Space is indefinite, unlimited, and of the extent which all bodies may be supposed to occupy.

Divisibility.— All bodies may be brought into the fluid state by heat, but there are other means by which matter may be divided. Stone, metals, and timber may have their particles separated by a blow, by friction, grinding, filing, sawing, splitting, &c. &c. The several divisions so obtained may be in many instances rendered smaller by sublimation; by passing the finest portions through sieves, and throwing them into water, they may be subjected to decantation; blowing will produce the same effect, the air put in motion by the bellows carrying the particles to a distance proportionable to their fineness; this is the case in all powder manufactories, and thus is corn winnowed from the chaff.

Sublimation is vapourising bodies by means of heat in close vessels, and condensing the vapour so formed by cold applications.

Inertia. — As matter in itself is inert or inanimate, it cannot produce motion, or change that position which is imposed upon it, so that it remains in perfect repose, unless acted upon by an animated mover, or weight or pressure be applied to it: when, however, put in motion, in a certain direction, it will continue to move in it, unless obliged to deviate by some efficient cause; nor will its rapidity increase unless some acceleration be given.

A weight or heavy body thrown from a height continues to fall with an accelerated movement derived from its own weight, which acts continually on it, in the same manner as when it is in repose, and this is rendered evident by the movement of a ball which, when thrown upwards, diminishes in rapidity instead of augmenting: a cannon ball propelled obliquely changes at each instant of time, the weight operating to bring it to the earth. *Inertia* obliges a body in constant motion, with a certain rapidity, and in a certain direction, to preserve its line of course, which would be uniform, and in a rectilinear direction, if nothing occurred to derange it.

Force.—This term is applied to causes which modify the actual state of bodies, or would do so, if other forces did not interfere to destroy the effect of the first: the resistance of the air, heat, and weight change the state of bodies: different effects of forces are produced: sometimes leaving bodies in a state of repose, sometimes changing their form, by breaking or impressing them with movement; at other times accelerating or retarding that which they possess, or changing its direction; when bodies suddenly change their state, either in direction or movement, it arises from an increased force, producing an effect in a smaller portion of time, the duration of which cannot be measured by the means we possess. The ball discharged from a gun will pass through a pane of glass, a door panel, a sheet of paper, with so much rapidity, that the parts carried away have not time to communicate movement to those adjacent.

A cannon attached to a vertical cord, and nicely balanced, sends the ball to its destination, in the same manner that it would do if mounted on its carriage; which is a proof that the cannon had not deviated in any appreciable manner before the ball had left it, although it recoiled afterwards. The forces which give motion are called *moving*; those that hasten movement *accelerating*, and those that keep it back, *retarding* forces.

Measure and Nature of Force.—When a body at rest, or free to move is drawn or forced forward, it may be said to be pressed in that direction; the effort is called pressure, and analogous to the force exercised in supporting a weight. Two forces are equal, when, being substituted for each other, and under the same circumstances, they produce the same effect, or destroy that of a third when opposed to them. A body suspended by a thread assumes a perpendicular direction; and if two forces be applied for the same purpose, they will be equal to each other, as well as to the weight of the body, and may be measured or compared by means of the balance, or other instrument used for that purpose, among which is the dynometer. The farther we remove a body from the surface of the earth, the less is its apparent weight; so that at the summit of a mountain, the body suspended to a thread will have apparently diminished in weight 1 part in 700 for a height of 3 miles. The nearer we approach the equator the greater is the diminution of weight, although not to so appreciable a difference as to be of importance in mechanics: the plumb line, or the weight at the end of a thread, is not, strictly speaking, perpendicular, nor are a succession of them in parallel lines, as they all tend towards the centre of the earth; but as the distance is so great, it is unnecessary to take the variation into our consideration. We may estimate weight as a constant force, and invariable in its direction, as far as concerns the labour of the mechanic.

The Manner in which Force acts upon a Body. — When force is applied to any point on the surface of a body, it exerts a pressure against the molecules nearest to this point; and the body is either compressed, or in some degree gives way. The molecules, when brought in closer contact, after the force is removed, in virtue of their elasticity, make an effort to return to their original state; by pressing against each other, the force is conveyed to the extreme molecule, and if this can be driven no further, then compression takes place, and the form of the body undergoes a change: should this extreme molecule have the power,

however, to move, it will advance, and the movement will be communicated to the parts of the whole body, and these approaching nearer and nearer, in consequence of a series of compressions, indicate clearly that time is necessary before any force can communicate its total effect; for rapidity of movement is not instantaneous, as has been too often supposed. The same happens when an inverse force is employed to destroy the movement of a body; the molecules nearest the point of action are first stopped, and then the others in succession.

As each molecule is to a certain degree elastic, it cannot be compressed without a reaction taking place, for the force which presses against a body is repulsed in the same manner as it is exerted in forcing that body forward; this reaction is equal, though contrary to, the action itself.

When a body is pressed by the finger, or drawn by a thread, or pushed with a rod, we have by the same effort pressed, drawn or pushed the body in contrary directions. In all cases, the action of the force is transmitted to the point of resistance by a series of reactions, equal and opposite, destroying each other: but we admit generally that the force applied to a given point exerts itself over the whole.

Inertia of Matter, measured by means of the Forces. — When an external force acts on a body free to move, or destroys the motion imposed upon it, the resistance offered is equal to the force applied; by this resistance we measure the inertia of matter; in the same body the resistance is increased, according to the degree of rapidity impressed or destroyed, and this quality is augmented in proportion to the matter contained in each body. If a weight be drawn by a cord, the cord extends, elongates, and perhaps snaps, when suddenly pulled; if it be suspended, and in the line of suspension a spring balance is introduced, the spring will indicate the weight of the body; this weight taken away, the spring will again resume its state when in repose; the variations of the movement of a body and the force of inertia are thus measured. This measurement may be expressed by making lines equal in length to the force, in pounds or any other weight; or a number of divisions marked upon a given line may show the intensity of the force; and thus mechanics may be studied by figures in geometry.

Equilibrium of Forces. — When two or more forces are applied, they reciprocally destroy each other, so that they leave the body to which they are applied in the same state as previous to their application, whether in action or repose; and if they neither modify the direction nor the intensity of the rapidity when the body is in motion, then there is an equilibrium between the forces. This equilibrium is static in the first instance, and dynamic in the second; if a cord be drawn or stretched with equal force at each end, it is in a state of equilibrium; but if a greater force be applied at one end, then it is dynamic; there is no *true* static equilibrium, the earth attracting all bodies to a certain degree.

Influence of Inertia on the state of Equilibrium. — When a body is acted on by several external forces, and preserves a uniform movement, it is considered in equilibrio. When the rapidity is augmented or diminished, the equilibrium has no place in these forces; but if regard be had to the force of inertia of the different molecules, and we substitute an exterior force equal to those originally applied, there will then be an equilibrium between all these forces: a horse drawing a carriage destroys at every instant the resistance offered to his action, and if his movement is uniform, all the obstacles presented by the inequality of the road are overcome: if his rapidity be increased, the inertia put in motion is added to the preceding resistance, and the horse causes an equilibrium to take place among all these forces: if, however, the rapidity be diminished, the inertia which keeps the carriage in motion adds its action to that of the horse, and destroys or maintains the resistances in equilibrio.

When two forces are directly opposed, the less will destroy the greater to an amount equal to its value. Three men pulling a cord in the same direction, with the force of 20, 34, and 50 pounds, in all 104 pounds; and two others pulling in an opposite direction, with a force of 24 and 38 pounds, total 62 pounds; the cord will really be drawn with a force of 104 — 62 or 42 pounds, acting in the direction of the three men.

Mechanical Labour of the Forces. — The most simple state of equilibrium is when two equal forces destroy each other, and this is the case in works of industry. To work is to overcome or destroy resistance, such as the force of adhesion, which exists between the molecules of bodies, the force of springs, of weight, the inertia of matter, &c., &c.: to polish a body by friction, to divide it into parts, to raise weights, draw a carriage, bend a spring, propel a ball, are all works in which labour is constantly renewed, to overcome the resistance offered: in mechanical labour, resistance is overcome at the same time that it is reproduced. To remove a portion of matter from a mass by means of any tool, it is requisite not only to produce an effect directly opposed to the resistance presented, but the tool must be made to advance in the direction of the resistance; the greater this advancement is, the greater will be the quantity of matter removed; at the same time it must be taken into account that the greater the length or thickness acted upon, the greater will be the resistance, so that the work increases with the intensity of the effort and the length of the direction.

Measure of Labour when the Resistance offered is constant. — Supposing the resistance to be uniform, as well as the effort, which is directly opposed to it, and that at the same instant of time it remains the same, it is evident that the work or labour is proportionate to the length of way made; if on a road it will become double or triple, in proportion as the carriage passes over it: so that if we take labour as unity, or that which vanquishes resistance along a yard of road, the total labour will be the number of yards passed over. But should the labour increase at each yard, so that the second should be double, and continue in this proportion, then the labour will be increased in a corresponding manner. As, for example, 1 pound for the first yard, 2, 3, 4 for the second; the labour for each yard would then be 2, 3, or 4 pounds: taking for unity that force which overcomes the resistance of 1 pound along 1 yard, any labour may be measured by the number of pounds, which express the various resistances of each yard run over. Suppose a moving power employed to draw a body along a horizontal plane, the labour must be sufficient to overcome the constant friction which exerts itself, and if this friction be equal to 40 pounds, and the distance passed over 100 yards, then the labour will be measured by multiplying 40 by 100 or 4000 pounds. The rate at which a body moves, or the length of time which it takes to move from one point to another, is called the velocity; and this is always proportionate to the force which puts it in motion. The absolute velocity is measured by the space over which the body moves in any particular period of time, as 10 miles in an hour; the distance divided by the time gives the velocity per hour. Space is also equal to velocity multiplied by the time; if the velocity be 10 miles an hour, and the time 10 hours, then 100 miles will have been passed over.

The Value of the mean Effort. — When we have found the value of the mechanical labour of a variable resistance for any length of way run over by its point of action, and divide that value by the distance, we obtain the mean effort of resistance; or the constant effort, which, being repeated along the road, will produce the same quantity of labour: we have already shown that for a constant resistance the labour is measured by the product of that resistance, and the total road passed over.

Various Examples of mechanical Labour. — When a mover is employed in pressing a spring, at each instant it developes an effort which increases as its point of action has gone over a greater distance in the proper direction: this effort may be measured for each position of the spring, or for each position of the point of action: we may then designate it as a curve, which gives laws to these efforts, and by approximation calculate the sum of the mechanical labour employed at each instant of time, which, united, compose the total labour. For example, the labour of drawing a body along a plane offering a constant resistance, and which is indicated by compressing a spring, the resistance of which varies at each instant of time. This may be applied to a horse working in a mill, a man drawing water from a well, sawing or planing timber, polishing metal, &c. The work done may always be measured by the efforts, equal and opposite, or those contrary to the resistance of the tool employed, the length of that resistance, if it be constant, or by the sum of the products which measure the partial labour, if the resistance be variable.

In seeking to appreciate mechanical labour, care must be taken not to confound that which the mover effectually expends, and that which immediately results from the work performed; for it is easy to imagine that a portion of the first effect is destroyed by other resistances than those arising from the work: it is only to this latter resistance that the measure of labour can be applied. To show this, we will instance the whitesmith, in the operation of filing a bar of metal, on which he must first lean sufficiently to make his file bite; he must constantly support the weight of the file, he must exercise another effort to make the file slide over the bar, and this, with a certain rapidity backwards and forwards to overcome the inertia of the matter contained in it, so that the quantity of work done is the result of all these varied circumstances. This apparent complication disappears when we separate from the result all that is not indispensible to it, bearing in mind what actually takes place, where the grains of metal are taken away by the file. We then only see a resistance which supposes an effort equal and contrary to the direction of the way which the point of action of the file describes, and the quantity of labour which is measured, as we have before described. The labour of the mover may be reduced to that only, by supposing the file placed flat on a level bar loaded with a certain weight, and that the mover is employed in regularly drawing this file in the direction of its length, taking into account the inertia in the first instance.

The most simple labour is that of raising a perpendicular weight, provided the inertia be not taken into consideration. The unit of labouring force is sometimes considered to be that which raises a pound one foot in height: a cube metre of water, which weighs 1000 kilogrammes, raised one metre in height, is the unit in France; and this is denominated a kilogrammetre. Bolton and Watt's dynamical unit was one-horse power, equal to raising 33,000 pounds one foot in height in a minute, which the French estimate at 75 kilogrammetres per second.

The metre is 3·28 feet, the kilogramme 2·2 pounds, the kilogrammètre 7·216 dynams, and the horse power is 525 dynams, which nearly coincides with Bolton and Watt's dynamical unit.

Mechanical power is the term used by Smeaton; *momentum of activity* by Carnot; *dynamic effect* by Monge, Hachette, Coulomb, and others, all signifying the quantity of action or mechanical labour.

It is evident that labour is judged of by its quantity, or rather that of the work performed, which must be proportioned to the mechanical labour required. Labour, then, is the quantity of action, which pays itself in force.

Labouring force is measured by the product of the resistance overcome, and the space through which it is overcome.

Parallelogram of Forces. Independently of the action of simultaneous forces, the action of force on a body, whether at rest or in motion, is always the same, and impresses on it the same degree of velocity in both circumstances. A body left to itself is moved by gravity with the same degree of velocity at each instant of time: when it leaves the state of rest by having motion imposed upon it by force of any kind. as a shell, in its passage through the air, it describes a parabola; the velocity of the projectile at each instant is always the *resultant* of the velocity which it received at the instant immediately preceding that which we have considered; and the very slight velocity which gravity impresses on it during the interval of time, also very small, separates these two succeeding instants: thus where two forces are applied to the same body, they will impress upon it at each instant, and simultaneously, the degrees of velocity common to each; and these degrees, according to the general laws of nature, are proportionate to the intensity of the forces.

A single force which is equivalent to two or more forces is called the resultant, and relatively to *it, they* are called the components. A force acting on a body at A, in the direction of A B, as well as in that of A C, when these forces are equal, and act together, the body will in the same time be moved through the distance A D, or the diagonal of the parallelogram. The forces in the direction A B, A C, A D are respectively proportional to the lines which represent them. The two oblique forces A B, A C, are equivalent to the single direct force A D, which may be compounded of these two, by drawing the diagonal of the parallelogram A D.

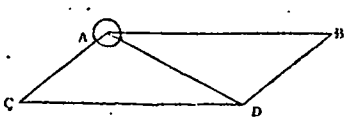


Fig. 1225.

A body acted upon by two forces at the same time will pass through the same point, as it would do if these forces were to act separately and successively: and if any new motion be impressed, this does not alter its motion in lines parallel to its former direction.

Suppose three forces A, B, C, acting against one another at the point D, and whose direction is on the same plane; if they are all in equilibrio their forces will be to each other respectively as the three sides of a triangle, drawn parallel to their lines of direction, D I, C I, C D. The three forces A, B, C, are to each other as the sines of the angles through which their respective lines of direction pass when produced.

D I : C I : : C D B : C D A

and C I : C D : : C D A : A D B.

It must be evident that if the force C alters its direction from that applied in either direction, its diagonal and corresponding sides are affected, the parallelogram D H C I is changed in form, and the whole proportions vary. The united effects of two forces moving in the direction of the sides of a parallelogram are expressed by a diagonal drawn in that figure.

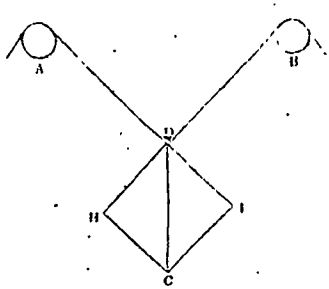


Fig. 1226.

If a body acts against another by any force whatever, that force is exerted in the direction of a line perpendicular to the surface on which it acts. Suppose the ball B strike the body C in an oblique direction, so as to form the angle A B D: the magnitude of the stroke will be directly as the velocity, and the sine of the angle of incidence A B D, and the body C receives the stroke in the direction E B, perpendicular to the surface D B.

The magnitude of the stroke is represented by B E, and the motion impressed on the body that receives it is equal to the magnitude of the stroke, and to the motion lost in the striking body.

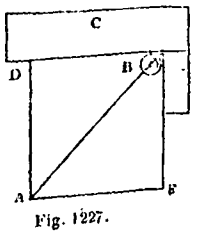


Fig. 1227.

If an elastic body A impinges a hard and elastic body, C F, at B, it will be so reflected from it that the angle of reflection will be equal to the angle of incidence. The motion at B, parallel to the surface, not being altered by the stroke, elastic bodies recovering their figure in the same time that they lose it by the stroke; therefore the velocity in the direction of B E is the same after as before the stroke, and we have two equal and similar triangles. But as no two bodies in nature are *perfectly* elastic, one angle will be more acute than the other: a non-elastic body striking another in a similar state loses half as much motion as if both were perfectly elastic; non-elastic bodies only stop, but elastic recede with the same velocity that they meet with.

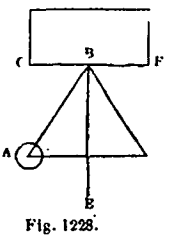


Fig. 1228.

On the force of Gravity.—The earth, whose diameter is about 8000 miles, has from its magnitude the power of attracting all smaller bodies to its surface; so that when put in motion they tend, if unopposed in their descent, in a straight line towards its centre: this is sometimes called the earth's attraction, or terrestrial gravity, and the force by which the body is attracted is called weight.

The force of gravity acts equally on bodies in motion and at rest: when put in motion it draws them down, and destroys in some measure the forces which put them into motion, and the same quantity of force is required to keep them in uniform motion directly upwards, suspended, or at rest; when they descend uniformly that force which is sufficient to prevent their acceleration in descending is equal to their weight.

When a heavy body falls from any height, as it approaches the ground it increases in velocity; this is rendered evident from the force with which it strikes the ground, that force increasing in proportion to the height from whence it has fallen, and also to its velocity at the moment it reaches the ground. The velocities of falling bodies are the accumulated effects of the attraction of the earth during the entire time of their descent: at each instant a new impulse is given which increases the velocity, so that the final velocity is the sum of all which have been communicated. Gravity is, then, a uniform force or attraction, which affects all bodies equally, whatever may be their position. The velocity of a falling body is as the time of its falling from a state of rest, the force of gravity being the quantity of matter.

All bodies falling by their own weight gain equal velocities in equal times, and when the same bodies are thrown or propelled upwards, they lose as much in an equal time: when a body falls through a certain space in a given time, it will afterwards descend through four times that space in the next similar period of time; through nine times that space in the third, sixteen times in the fourth, &c.: or, to ascertain the space through which a body will fall in a given number of seconds, multiply the space in the first second of time by the squares of the total number of seconds it was in falling; thus the spaces through which a body falls is as the square of the time from the commencement to the fall, or the velocity is as the square root of the height fallen, and it is absolutely necessary, before we can compute any velocity, that we should know how much it would fall through in a second of time. The velocity acquired in a second, and the space fallen through in a second, are the elements upon which the whole calculations are formed: when one of these elements are known, the other may be immediately found, as there is a remarkable relation between the space through which a body falls, and the velocity it acquires in any given time. In the latitude of London a body will fall in a single second 193 inches, or about 16 feet. Taking any equal parts of time, the spaces described by a falling body in each successive part of time will be the odd numbers 1, 3, 5, 7, 9, 11, &c.

The spaces, velocities, and times may be judged of by the following table: the space fallen through in the first second of time is considered the unit of length:—

Seconds from the beginning of the Descent.	Velocity acquired at the end of that Time.	Space fallen through.	Space fallen through in the last second of the Fall.
1	2	1	1
2	4	4	3
3	6	9	5
4	8	16	7
5	10	25	9
6	12	36	11
7	14	49	13
8	16	64	15

Between the three quantities, the height, the time, and the final velocity, there are fixed relations. The time counted from the commencement of the fall and the final velocity are

in proportion to one another; for as one increases, so does the other. The height being equal to half the space which would be moved through in the time of the fall with the final velocity, must have a fixed proportion, and the time and final velocity are proportional to the product of the two numbers which express them.

The phenomena of falling bodies were experimented upon by Mr. George Atwood, who constructed for the purpose a very ingenious machine, which still bears his name.

The gravitating forces of bodies are to each other, first, directly as their masses, and, secondly, inversely as the squares of their distances: for if the mass of one body is double that of another, its gravity will be doubled, and with a distance twice as great, its gravity will be as many times less. Putting M and m for the masses; D and d for the distances, and G and g for the forces of gravity of two bodies; first we have $G : g :: M : m$:

$$\text{Or, } G = \frac{g\,M}{m}, \text{ and if } g = 1,\ G = \frac{M}{m}.$$

$$\text{Secondly: } G : g :: d^2 : D^2; \text{ or, } G = g \cdot \frac{d^2}{D^2}; \text{ and if } g = 1, \text{ and } d = 1,\ G = \frac{1}{D^2}$$

$$\text{From whence it follows that } G : g :: M\,d^2 : m\,D^2;$$

$$\text{Or, } G = g\,\frac{M}{m}\,\frac{d^2}{D^2}; \text{ whence, if } m \text{ and } d \text{ are} = 1,\ G = g \cdot \frac{M}{D^2}.$$

The latter expression is usually taken for the above laws, M representing the attracting mass, and D the distance at which it acts upon some other body, as compared with the attracting force g of this second body, whose mass is equal to 1, and whose distance is equal to 1, which are considered the units of measurement.

Terrestrial gravitation is the attraction exercised on all bodies by the earth; and occasions the common musket-ball, which proceeds at the rate of 1280 feet in a second, or the 24 pound cannon-ball, which has double that velocity, to fall at last to a place of rest.

The Centre of Gravity of a Body is a point through which a single force, equivalent to the gravitation of all its particles, passes, and in whatever situation the body is placed, its centre of gravity tends to descend in a line perpendicular to the horizon, called the line of direction of the weight. If a line be drawn from the centre of gravity of a body perpendicular to the horizon, and this perpendicular fall within the base upon which the body rests, it will stand, but if it falls without the base the body will fall down.

Hence it follows that if the centre of gravity of a body be supported, the whole body is supported, and the centre of gravity must be considered as the place of the body: if it be sustained by any lever or beam, its place is at the point where the beam is cut by a line drawn from the centre of gravity perpendicular to the horizon.

All the gravity of a body, or the force with which it endeavours to descend, being collected into the centre of that body or its centre of gravity, whatever sustains that centre of gravity sustains the whole weight, and the descent of a body must be estimated by the descent of its centre of gravity. Also the larger the base is upon which a body stands, and the farther the centre of gravity lies within it, the firmer will it stand, and the more difficult will be its removal. If, on the contrary, the centre of gravity be moved out of this situation, and made to approach to the extent of its base, its tendency to fall will be increased: a body laid upon an inclined plane, and having one end gradually elevated, will continue to slide as long as the perpendicular falls within the base; but if the perpendicular fall without it, it will roll over.

The centres of gravity of plane figures and solids are determined—

In the Triangle, by drawing two lines from any two of its angles to the middle of its opposite sides; the point of their intersection is the centre of gravity; the distance, therefore, of the centre of gravity from the vertex is two-thirds of the line bisecting the opposite side.

In the Trapezium, by dividing it into triangles, then finding the centre of gravity of each, and uniting the centres so found; the point of their common junction is the centre of gravity sought.

For the Arc of a Circle, as $\frac{1}{2}$ arc : sine of half the arc :: radius : to the distance of its centre of gravity from the centre.

For the Sector of a Circle, as arc : chord :: $\frac{2}{3}$ radius to the distance of its centre of gravity from the centre: for the parabolic space the distance of the centre of gravity from the vertex is at two-fifths of the axis.

In the Cones and Pyramids, the distance of the centre of gravity from the vertex is three-fourths of the axis.

In a Paraboloid the distance of the centre of gravity from the vertex is at two-thirds of its axis.

For the Segment of a Sphere let r be radius, x = to the height of the segment, then the distances of the centre of gravity from the vertex is $\frac{8\,r - 3\,x}{12\,r - 4\,x}$.

If two weights on any machine are in equilibrio, and moved by any means, the centre of gravity of the weight and the power will always be in the same horizontal right line: in the lever the centre of gravity is at the fulcrum; and therefore neither ascends nor descends.

In the wheel and axis, and in the pulley, the weight and power approach or recede from each other by spaces which are reciprocally as the bodies, and their centre of gravity is therefore at rest.

Upon the inclined plane, the perpendicular velocities of the power and weights are reciprocally as their quantities. and the distances of the centre of gravity from each being in the same ratio, is also at rest.

In the combination of any of these powers, or of any machine whatever, where the equilibrium continues, the ascent and descent of the power and weight being reciprocally as their quantities, the centre of gravity neither ascends nor descends.

To show the value of ascertaining the centre of gravity in a body in the arts of construction, we will suppose a piece of timber supported at the two ends B and C, as in the following diagram. If G be the centre of gravity of the whole weight sustained, and the line F G H be drawn perpendicular to the horizon, and C F and B H drawn, then the weight of the whole body is as F H; the pressure at the top C, as B H; thrust of the pressure at the base B, as F B. The pressure and the thrust are also in the direction of the respective lines which represent them. If the beam support any weight, the beam and weight must be considered as one body, whose centre of gravity is G. Then the end C is supported by the plane B C E, and the other end B may be supposed to be sustained by a plane perpendicular to B F; therefore the weight and forces at C and B are respectively as F H, B H, and F B. The angles B C F and B D F are right angles, and a circle described upon the diameter B F will pass through C D.

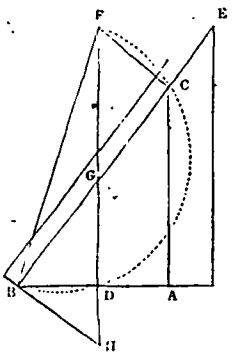


Fig. 1229.

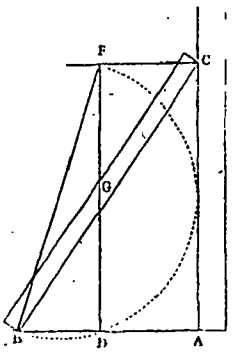


Fig. 1230.

If B C be any beam bearing any weight, G, the centre of gravity of the whole, and if it lean against a perpendicular wall C A, and be supported in that position, draw B A, C F, parallel, F G D perpendicular to the horizon, and draw F B.

Then the whole weight is represented by the line - -	F D
The pressure at the top, C, by - - - -	B D
Thrust at the bottom, B, by - - - -	F B

and the same by the several directions.

If the point which constitutes the centre of gravity be supported by a force equal to the weight of the body, it will remain in equilibrio in every possible position; and if the centre of gravity be either vertically above or vertically below the point of support, the body will be in equilibrio, but will not, as before, be indifferent to any position. When the centre is vertically above a point of support, the smallest inclination will altogether destroy the equilibrium; when it is vertically below a point of suspension, if the equilibrium be disturbed, it will after some oscillations be restored.

If a body rest upon a horizontal plane, and the vertical line passing through the centre of gravity be within the base, as we have already seen, the body will stand, if without it will fall; and when that line is within the base, the farther the point in which it meets it is from the perimeter on any side, the firmer will be the stability of the body, for the weight may be considered as acting entirely on the centre of gravity; consequently, the more distant any point in the perimeter of the base is from the vertical of the centre, the longer is the vertical lever by which the weight acts, and the greater the momentum to resist that of a given force similarly applied, tending to produce a rotation about an axis passing through that point. When the centre of gravity is high, the body is more easily overturned than it would be were the centre lower: a carriage loaded will overturn more readily on a declivity, and when the weight is piled up very high, the chance of accident is still further increased, because its centre of gravity is more easily thrown outside its base, or beyond the wheels or points of support. In every body possessing weight, there is a point through which the resultant of the gravitation of its individual particles will pass, whatever be the position of any given points in it with respect to the constant vertical direction of this force, that point is the centre of gravity.

If a heavy beam, or one bearing a weight, be sustained at C, and movable about a point C, whilst the other end B lies upon the wall B E, and if H G F be drawn through the centre of gravity, G perpendicular to the horizon, and B F, C H perpendicular to B C, and C F be drawn, then—

The whole weight will be equal to	H F
Pressure at B	H C
Force acting at C	C F

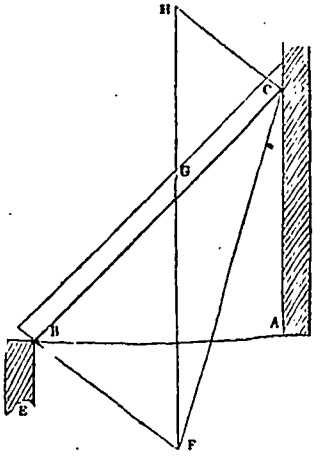


Fig. 1231.

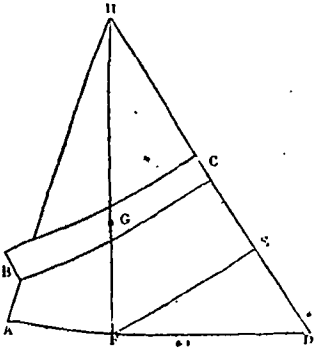


Fig. 1232.

If a heavy beam, B C, whose centre of gravity is G, be supported upon two posts, B A and C D, and be movable about the points A, B, C, D, and if A B, D C produced meet in any point, H, of the line G F drawn perpendicular to the horizon, and if from any point F in the line G F, F E be drawn parallel to A B, then—

The whole weight will be represented by the line	H D
Pressure at C	H E
Thrust at B	E F

and in these directions.

By the construction of these four diagrams the triangle of pressure is formed, representing the several forces in which the line of gravity, or the plumb line, passing through the centre of gravity, measures the absolute weight, and the other sides the corresponding pressures.

The Action of Bodies when placed over each other. — When two bodies touch each other at the point of contact, a depression or sinking may be imagined, perpendicular to the surface of contact, which indicates the reaction of the two bodies in the perpendicular line common to both: suppose, for instance, that a body A be solicited by forces the resultant of which is confounded with that perpendicular, and that the other body B remains fixed, the reaction of the latter will destroy the resultant, and the body A will remain in repose: but it is evident that the equilibrium will subsist if the body B be replaced by a force equal to the reaction which it exerts against the body A, if this latter be considered as free, and solicited by this new force concurrently with the other forces given. This property, that all bodies resist each other according to the common perpendicular which passes through their point of contact, extends in most cases to where one body is placed on others: the reaction of the latter are so many true forces at the respective point by which the first bodies rest on the other, and thus the equilibrium is restored or brought back to conditions analogous to those which would have taken place if it had been free. A simple instance of this is shown by a body placed on a single point, or by several on a plane.

When a body rests on a plane at a single point, and is drawn by any forces whatever, their resultant must be perpendicular to the plane, and must pass by the point of support. The condition of passing by the fulcrum will not be sufficient for it alone, for if this resultant be decomposed in two forces, the one perpendicular to the plane, and the other situated in the plane, both passing by the point on which it rests, the first will be destroyed by the resistance of the plane, but the other component will cause the body to move along

the plane, and they will no longer be in equilibrio: thus the equilibrium of a body which rests on a plane by a single point is submitted to two conditions; first, the result of the forces applied to bodies passes by the point of support, and, secondly, its direction is perpendicular to the plane.

Equilibrium of an inclined Plane. — Let us represent any plane cut perpendicularly to its horizontal, and following the line of its greatest inclination, A B. Although this plane be supposed to be indefinitely prolonged, its inclination is sufficient to define its base A C and its height B C. Let us imagine a heavy body placed on this plane of which G shall be the centre of gravity: the equilibrium of this body in the plane will require, first, that the resultant of its weight should pass by one of the points of the base which supports the body; secondly, that that resultant be perpendicular to the plane: this latter condition cannot be generally satisfied with regard to any plane whatever, because the action of gravity is always vertical; hence this action will be decomposed into two others, the one perpendicular to the plane, which will be destroyed by its resistance, and the other parallel to the plane, which will cause the body to move or descend according to its length. We must, however, remark that if the vertical of the centre of gravity meets the interior of the base of support of the body, this latter will only slide in the direction of the plane; but it will roll if the vertical falls without the base. This will happen with a base, because the vertical always passes outside its point of support on the plane.

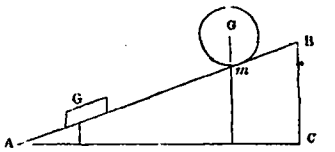


Fig. 1233

Let us suppose that a force, p, parallel to the plane, is opposed to the descent of the ball: call P the weight of the latter; we know that the body ought to remain in equilibrio under the action of the two forces p and P; consequently their resultant, G M, will be perpendicular to A B, and will pass by the point of support m, and then let G M be the intensity of this resultant; it will be such that the sides of the parallelogram G G′ M N will represent, the one G G′ equal M N the vertical force P, and the other G N the force p, parallel to A B. The triangle G M N is similar to the triangle A B C, for G M and M N are perpendicular to A B and A C; moreover they are rectangles, the one in G, the other in C: we shall have the proportion

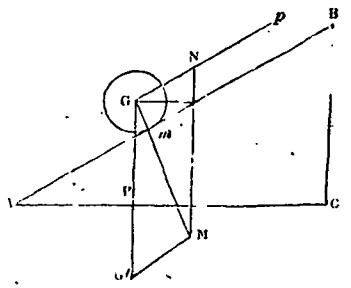


Fig. 1234.

$$\text{G N} : \text{M N} :: \text{B C} : \text{A B},$$
$$\text{Or } p : \text{P} :: \text{B C} : \text{A B}.$$

Then the force parallel to the plane which holds the body, is to the weight of this body, as the height of the plane is to its length: and we have

$$p = \text{P} \times \frac{\text{B C}}{\text{A B}}.$$

Suppose, instead of drawing in the direction of the plane, the force p, which retains the body on the plane, was horizontal and acted in the direction of the power, which prevents a nut from descending along the screw; G M, the resultant of the weight of the body and of this new force, will not be the less perpendicular to A B; and the triangle G M N, representing the two forces which draw the body as well as their resultant, will be similar to the triangle A B C: but as G N is perpendicular to B C, and the right angle of the first triangle is in N, we shall have the proportion, as G N : M N :: B C : A C;

Or, p : P :: B C : AC,

which shows us that the horizontal force retaining the body in the plane is to the weight of the body as the height of the plane is to its base: or, that

$$p = \text{P} \times \frac{\text{B C}}{\text{A C}}.$$

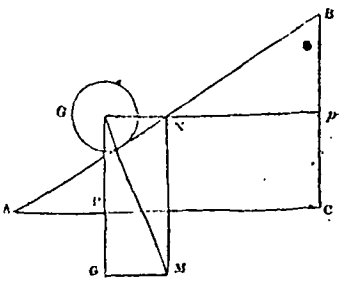


Fig. 1235.

It will be remarked, that in the value of p the numerator is the same for two cases in proportion to the height of the plane; but the denominator is only the side of the plane parallel to the force applied.

Quantity of Work on an inclined Plane.—The inclined plane is a machine of the greatest utility in the arts, and facilitates the removal of the heaviest burthens to a considerable height. If, for example, it be required to build a tower of stone, a number of men would be necessary to raise the materials vertically; but by means of slopes or inclined planes, men, horses, or carriages could readily ascend it, and the power required to draw the weights would be much reduced.

To move a stone along an inclined plane A B, the workmen are accustomed to turn it on its edges perpendicular to the inclinations, or if it be cylindrical, they roll it along, so that in its different operations the resistance of the friction is avoided; the effort, F, which is here parallel to the length of the plane, A B, has then only to overcome the resistance of the weight, P, of the body; and as we have shown, we shall have

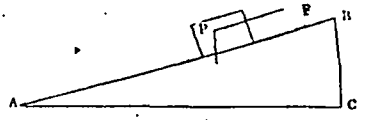


Fig. 1236.

$$F = \frac{B\,C}{A\,B} \times P.$$

If the inclination of the plane be such that its length, A B, is 100 times its corresponding height, B C, the effort required to be exercised against the body is in the proportion of 1 to 100, and consequently the labour is the same whether the body be raised directly or along an inclined plane, this latter having no other use than that of facilitating the elevation of the burthen. When a body descends along an inclined plane, its relative gravity, or the force which accelerates its motion, is to the absolute force of gravity, as the height of the inclined plane is to its length; or, the force urging the body to descend in the direction of the plane, is to the whole force of gravity, as the height of the plane is to its length.

An inclined plane is any plane surface which forms an angle with the horizon, and is measured by A B C. The line A B is the length of the plane B C, the length of its base. C A, its height.

There is, then, in an inclined plane an equilibrium when the power is to the weight, as the height of the inclined plane, is to the length of its base multiplied by the cosine of the angle which the direction of the power makes with the inclined plane.

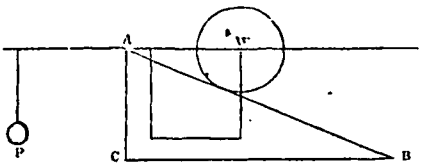


Fig. 1237.

When a body W is placed upon a horizontal plane, it is obvious that it cannot be in equilibrio, unless a perpendicular let fall from its centre of gravity cuts the plane within the base of its body: when the plane becomes inclined to the horizon, the same condition is necessary, and another force, P, is requisite to prevent it sliding down the plane in virtue of its gravity. In order that an equilibrium may take place, the resultant of the two forces P and W must be in a line perpendicular to the plane, and their direction must lie in the same plane, and as the direction of W is in a vertical plane passing through the centre of gravity of the body, the direction of P must be in the same plane.

The weight, power, and pressure on the plane are then respectively as radius, the sine, and cosine of the plane's elevation: for if a cylinder be sustained upon an inclined plane by a power holding one end of a cord parallel to the plane, whilst the other end is fixed, the power is to the weight of the cylinder, as half the height is to the length of the plane: this is obvious, for half the relative weight of the cylinder is sustained by the end of the rope which is fixed.

The Wedge is a solid with three planes inclined to each other, and two triangular sides: to free it from friction the faces should be polished, and the force which acts upon it is directed perpendicularly. That the three forces acting on the three planes may be in equilibrio, each of them must be in proportion to the length of the plane on which it acts, and they must be applied at such parts that their directions meet in one part; otherwise they will be in opposition, and produce a rotary motion.

The shore C, for instance, when placed against a smooth vertical surface, as the wall of a building, or employed to raise a weight by means of any force applied at the foot by drawing it along the surface, A B; the horizontal force applied will be to the weight, as the distance, A B, is to the perpendicular height of the wall: and on this principle the equilibrium of arches, domes and roofs is estimated.

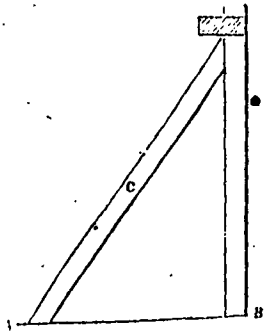


Fig. 1238.

The edge C, called the cutting edge of the wedge, is the most acute angle of the triangle A B C. The face B A is the head, and A C and B C are the sides.

The use of the wedge consists in driving it, by the cutting side C, into the substance to be split, so that when driven it rests on its sides in two places, *a*, *b*. Suppose the force F, which causes it to descend perpendicular to the head, (if it were oblique, the wedge would turn,) has the power of resisting or overcoming the matter to which the wedge is applied, which resistance may be represented as two forces Q and R applied at *a b*, perpendicular to the respective sides A C and B C. The force F, which produces the equilibrium, will be equal, and directly opposed to their resultant, and as this passes by the point of concurrence of the forces Q and R, it is necessary that the three forces F, Q, and R should be in the same point, or the wedge would be overthrown. If these resistances then be given, the diagonal of the parallelogram constructed on their intensities, and at their point of concurrence, will give the intensity of the force F to be perpendicularly applied at the head of the wedge required to overcome these resistances. Taking on the direction of Q, from the point O, a line or distance O*m*, equal to the force, and carrying through the point *m* a line perpendicular to B C, as *m n*, we shall have the triangle O*m n*, two sides of which represent the two resistances Q and R, and the third their resultant or the power F, which is equal or directly opposed to it: the triangle O*m n* is equal to the angle C, the angle *m n* O is equal to the angle B, and the angle *m* O*n* is equal to the angle A. Thus the sides O*n* and A B, opposed to these angles, are homologous; the same is the case with the sides *m* O and A C, and the sides *m n* and B C; we shall then have the following proportions; O*n* : *m* O : : *m n* : : A B : A C : B C, or, replacing the dimensions O*n*, *m* O, *m n* by the forces F, Q, and R, which they represent, F : O : R : : A B : A C : B C, which indicate that in the equilibrium of the wedge, the perpendicular power at the head, and the two resistances perpendicular to the sides, are proportioned to that head and these sides; as when a force is applied to drive it, that force is to the resistance which the parts of the body oppose to it, as the head of the wedge is to the sum of its sides.

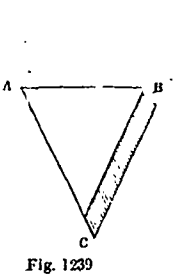


Fig. 1239

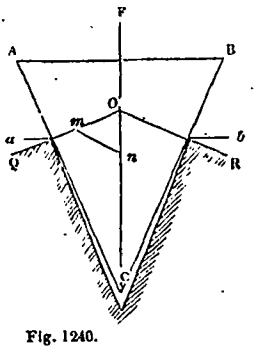


Fig. 1240.

Several forms are given to the wedge; among them is one resembling the triangle A B C, with the rectangle in A, the points of support being at *a* and *b*, and the resistances in the direction Q and R. The power F, which is perpendicular to *a b*, cannot concur at the common point of the direction of these resistances, unless they are applied according to the direction of the line F*b*, parallel to the side A C, and passing by the point of application of the resistance which is perpendicular to the hypotenuse.

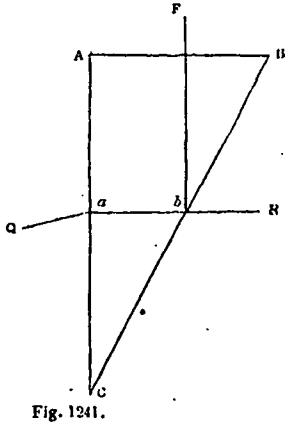


Fig. 1241.

In the example where the wedge is an *isosceles triangle*, which is the common form given it, we have A C equal to B C, and, agreeable to what has been already stated, the relations which satisfy the equilibrium are

$$Q = \frac{F \times AC}{AB}, \text{ and } R = \frac{F \times BC}{AB}$$

We see, on account of A C being equal to B C, we have Q = R, whence we have the proportion of

F : Q : : A B : A C.

When it is required to split bodies, wedges are used, the heads of which are small in proportion to their sides; if ten times less, as A B is the tenth of A C, F will be the tenth of the reaction, Q, to be overcome; thus the advantage drawn from the wedge is, that in diminishing the head, or the angle of cutting, we can with a small force overcome considerable resistance, as ten times or an hundred times, by making the head a tenth or an hundredth part of its side.

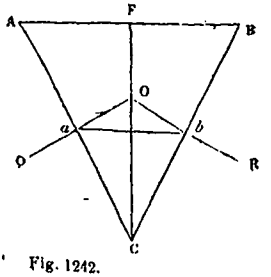


Fig. 1242.

Divers forms of the wedge are given to workmen's tools, and great loss of labour is occasioned by those most constantly in use, which have not always the prismatic form: when they are pyramidal, having three or four faces, the equilibrium between the power and the resistance is analogous to those of the prism; the first is equal and opposed to the resultant of three or four forces, which depend on the length of each face, and the sides which form the head.

The wedge is also a truncated prism, and often nothing more than a cone with a cylindrical head; but the condition of its equilibrium is the same as that of the isosceles wedge, viz. the power is to the resistance, as the diameter of the head, is to the length of the side of the cone.

Chisels, knives, nails, files, &c. are half flat prisms, the surfaces of which are striated or cut into furrows at a certain angle, and crossed at another, so as to form small pyramids or wedges, the points of which carry off the particles to be filed. Saws are an assemblage of wedges, the lower face of which is slightly inclined towards the cutting edges and in the thickness of the blade; one tooth also inclines differently to the other, viz. one to the right, the other to the left, that the saw may clear itself, and work more freely. All wedges act on their cutting side, or on their pointed extremities, and there is a proper angle for every tool according to its use, which practice can alone determine. The chief matter for the workman to consider, when he is setting a cutting instrument to act upon any surface, should be that he endeavour to make its end form the least possible angle with the face to be cut; it should, therefore, be kept nearly parallel with the surface it is employed upon, and should it be required to be made very sharp, the acuteness given to it must be obtained by taking away from the front part of the cutting instrument against which the shavings slide. The carpenter's axe has the bevelled surface outwards, and the flat side is that which is placed against the wood to be cut, so that the angle between the face of the tool next the wood and its surface forms the least angle possible.

The Screw depends for its action on the same principles as those of the inclined plane, and to have an idea of the form of the square thread screw, suppose a cylinder B C E D

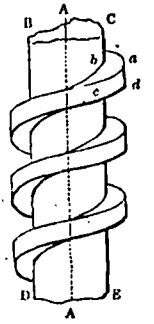


Fig. 1243.

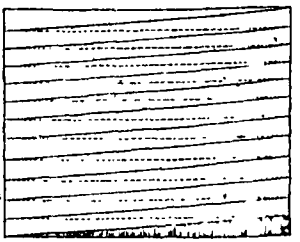


Fig. 1244.

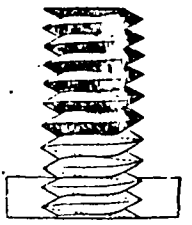


Fig. 1216.

drawn with the axis at A vertical. If there be attached to the surface of this cylinder or newel a rectangle, as *a b c d*, and which represents the profile of the thread of the screw, when the cylinder turns on its axis, this rectangle will form an annulus or ring, as long as it remains in a horizontal position: but supposing when it turns, the rectangle is made to descend, and for each quarter of a revolution it descends a fourth of the vertical height, a square thread will be projected on the newel, called a helix; when this has passed entirely round its height, it is termed the step of the screw, and is measured by the interval *a a'*, between the upper surfaces of two consecutive threads; the inclination or stiffness of the helix diminishes towards the external edge of the thread. When this has been formed, another body, cut in an opposite manner, and called the nut is applied to it; these together have a double movement of rotation, and act as on an inclined plane.

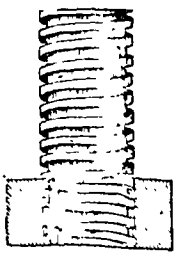


Fig. 1246.

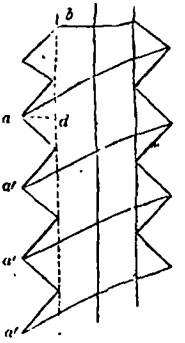


Fig. 1247.

The screw is nothing more than a cylinder, *b*, having a rectangular or triangular prism, as *a d*, wrapped or coiled round it, in such a manner that one of the faces of the prism is

applied to the convex or concave surface of the cylinder, and one of the sides of the prism always forms an acute angle with the axis of the cylinder, this angle being everywhere the same.

To raise a weight by the nut and screw, the first may be fixed, and the latter left free, or the reverse; in the first instance a lever is applied to the head, which not only turns in the nut, but raises the weight Q attached to its extremity; but when the screw has the nut movable, the power is so applied, that in turning the nut round the screw, it is elevated, raising at the same time the weight attached to it, as in the press.

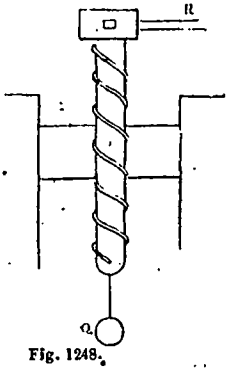


Fig. 1248.

Calling F the power, and Q the resistance to be overcome, it is evident that the first should act in the plane of the movement of its lever, or perpendicular to the axis of this movement, as in the wheel and axle; and if we abstract the friction, its labour should be equal to that of the resistance produced in the same time. It must be remarked that when this latter rises to a certain height, the point of application of the power must run over a certain arc, and in virtue of the property of the screw, the relation between these two quantities is always the same at the end of any given time, whatever may be the height to which the resistance has mounted, and the arc described by the power, provided that the arc and the height be simultaneous. We will now consider what takes place in a complete revolution: the power has described a circumference, whilst the resistance is raised one turn of the screw. If we call h the height of the turn, and R the distance from the point of application of the power of the axis, h and 2 P R will be the space described by the resistance Q, and by the power F in their proper directions; thus F and 2 P R will be the labour of the power, and $Q h$ that of the resistance at the end of a complete revolution, and we shall have for the condition of the equilibrium independently of friction,

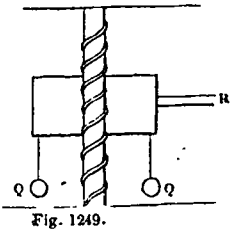


Fig. 1249.

$$F \times 2\,P\,R = Q h, \text{ or}$$
$$F : Q :: h : 2\,P\,R,$$

which indicates that the power is to the resistance, as the turn of the screw is to the circumference described by the point of application of the power: so that the power of the screw increases as the distance between the threads diminishes.

In the endless or perpetual Screw, there will be an equilibrium, when the power is to the weight, as the distance of the threads multiplied by the radius of the axle, is to the distance of the power from the axis of the screw multiplied by the wheels' radius. Suppose P the power, and x its effect on the toothed-wheel: let R be the radius of the wheel, D the distance between the threads of the screw, r the radius of the axle, W the weight, and C the circumference described by the power,

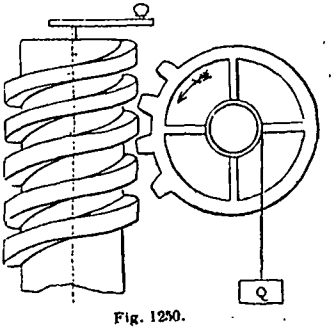


Fig. 1250.

$$P \times C = x \times D;$$

and by the properties of the wheel and axle,

$$x \times R = W \times r:$$

multiplying these equalities,

$$P \times C \times x \times R = x \times D \times W \times r;$$

we then have $P \times C \times R = W \times D \times r$,

or, $P : W :: D \times r : C \times R$.

The power, then, is to the weight, as the distance between the threads multiplied by the radius of the axle, is to the circumference described by the power multiplied by the radius of the wheel.

The Lever is of three kinds, and may be called an inflexible bar, capable of moving round a fixed pivot or fulcrum; its properties are various.

A lever of the first kind has the power and the weight on opposite sides of the fulcrum, as in the balance, steelyards, scissors, &c. Supposing two equal weights fixed at the ends of the equal arms of the lever, it is evident there will be a perfect equilibrium, since there is no reason why either should preponderate.

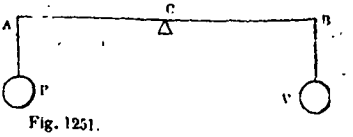


Fig. 1251.

$$P : W = B C : A C.$$

In a lever of the second kind, the weight is placed between the power and the fulcrum, as in cutting instruments which move round the point of the blade, &c.

$$P : W = BC : AC.$$

In a lever of the third kind, the power is placed between the weight and the fulcrum, as in fire-tongs, &c.

$$P : W = BC : AC;$$

hence we have

$$P = \frac{W \times BC}{AC}$$

$$W = \frac{P \times AC}{BC}$$

$$AC = \frac{W \times BC}{P}$$

$$BC = \frac{P \times AC}{W}.$$

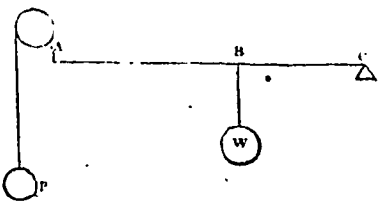


Fig. 1252

Fig. 1253.

The weight supported by the fulcrum C is equal to the sum of the power and weight, or P + W, when they act on different sides of the fulcrum, and therefore in the same direction; and to the difference, P − W, when they act on the same side of the fulcrum, and therefore in different directions. If the power P is shifted along the arm C A of the lever A B of the first class, the weight W, which is capable of maintaining an equilibrium, will be proportionate to C A, the distance of the power P from the fulcrum; for since P : W = B C : A C, we have W : A C = P : B C; and if a be another value of W, and a C another value of A C, we shall then have $w : a\,C = P : BC$. In a lever of the second kind the power must be less than the weight, since it must be further from the fulcrum; and in one of the third kind it must be greater than the weight, as it is nearer to the fulcrum. When the centre of gravity of the lever or bar is not immediately over the fulcrum, the weight of the bar must be taken into account. Of levers of the first kind there are many examples, as the crowbar, scissors, snuffers, &c., where two levers are riveted together: in elevating a ladder the first process partakes of a lever of the second kind, and afterwards of the third. When a man raises a stone by the application of the crowbar resting on a fulcrum between himself and the stone, he presses down the end of the lever, and the utmost force he can apply is equal to the whole weight of the body; but when he thrusts the lever under the stone so that its extremity bears on the ground, it becomes a lever of the second class; and in order to raise the stone he must draw the end of the lever upwards, and in this direction a powerful man can exert a force equal to twice his weight.

The Roman Steelyard is usually formed of a bar of iron resting upon an edge or pivot, and having one arm longer than the other. To graduate this machine or the arm C B: let us suppose M to be the weight of it when united to its centre of gravity u, N the weight of C A united in its centre of gravity v, and O the weight of the scale: let P, P′, P″, be the different weights employed: an equilibrium is obtained by placing the constant weight, W, at the different distances a, b, c; consequently, there will be an equilibrium in the following cases:—

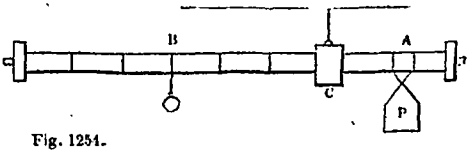


Fig. 1254.

$$P \times CA + N \times Cn + O \times CA = W \times Ca + M \times Cm;$$
$$P' \times CA + N \times Cn + O \times CA = W \times Cb + M \times Cm;$$
$$P'' \times CA + N \times Cn + O \times CA = W \times Cc + M \times Cm.$$

By subtracting the first equation from the second, and the second from the third, we have

$$P' - P \times CA = P \times ab$$
$$P'' - P' \times CA = P \times bc$$

$$ab = \frac{\overline{P' - P} \times CA}{P}$$

$$bc = \frac{\overline{P'' - P} \times CA}{P} \text{ &c.}$$

If the weights are in arithmetical progression, the distances ab, bc, will be equal, or form a scale of equal parts; and if ab be made equal to C A, then $W = P' - P\,W = P'' - P'$, &c. or the counterweight equal to the difference of the arithmetical progression of the bodies

weighed. In constructing a steelyard for practical purposes, the arm should be made sufficiently strong to prevent its bending, and it is necessary that the scale be graduated by experiment: supposing it is required to graduate the bar to indicate pounds, let one pound be suspended at P, and let the counterpoise be moved until the bar rests in the horizontal position; then try two pounds in the same manner: these two divisions being established, let the whole length of the bar be divided into equal divisions, and each division will give the number of pounds it will sustain; care being taken that the centre of gravity of the bar is at or under the fulcrum on which it is suspended.

The Danish and Swedish Steelyard is a bar or lever, with a constant fixed weight at one extremity, and a scale for holding the body to be weighed at the other. The point of suspension, therefore, varies, and is usually a ring moving along the bar, and placed in the position where the equilibrium takes place: for instance, suppose the weight, W, is that of the whole apparatus, with the exception of the ring, to be united in its centre of gravity; D and P, to be that of the body to be weighed. An equilibrium will take place, when $W \times CD = P \times CB$, which, since $CD = BD - CB$, gives

$$CB = \frac{W \times BD}{W + P},$$

from which the lever may be readily graduated. There are many applications of the principles of the lever to the balance for commercial purposes, and the sensibility of a pair of scales is made much more delicate, the more the length of the arms is increased, and the weight of the bar is diminished. The bent lever balance is graduated upon a quadrant attached to it, and an index which is acted upon by the body to be weighed. Supposing the scale be loaded successively, the divisions on the quadrant may be made to exhibit the respective weights by noticing the successive positions of the index.

The Pulley will have an equilibrium when each of the two powers is to the weight, as the radius of the pulley is to the arch of the circumference, which the rope surrounds. Let the powers, P, P, attached to the ropes which pass over the circles, M, N, and round the pulley, CE, whose centre is D, be in equilibrio with the weight W;

$$\text{then } P : P' :: W = CD : DF, CE.$$

P and P′ being equal, and in equilibrio, may be represented by the equal lines WA and WB; then drawing AF parallel to MW, and BF parallel to NW, the diagonal, WF, will represent the resultant of the two powers, P, P′: but as this resultant is in equilibrio with the weight, W, acting in the same direction FW, we shall have WF for the measure of the weight, W. By joining CD, DE, and drawing CE, two isosceles triangles are formed, WBF and CDE, which are similar, because the angles A and D comprised between equal sides are both the supplement of the same angle, CWE. The figure CDEW, which is quadrilateral, having C and E right angles, we have $WB : BF :: WF = DC : DE : CE$; therefore P : W or P′ : W as radius, is to the chord of the arc embraced by the rope. Each of the powers is to the weight, as radius is to twice the cosine of the angle which each rope forms with the direction of the weight. As the angle DCH is equal to CWD, CE is equal to twice its cosine, or twice CH.

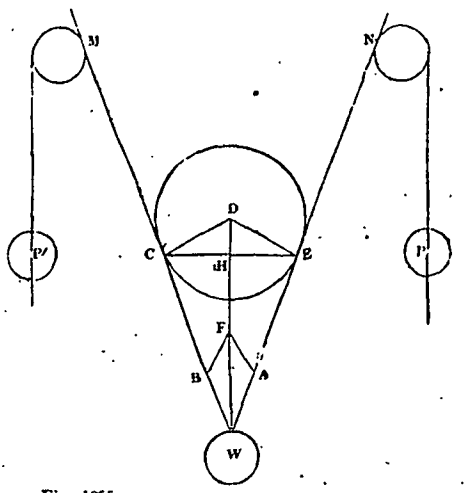


Fig. 1255.

The pulley is a cylindrical piece of wood, or any other hard substance, with a groove cut out of its rim for the rope to pass over. The cylinder moves round an axis, which works in a frame called the block. A system of pulleys, or a number combined together, called a muffle, is either fixed or moveable, according as the block which contains the pulleys is so. When a rope used to transmit force has its direction altered, if the angle be too sudden, the probability is that it will break; instead, therefore, of bending it over a single angle, the change of direction is generally produced by deflecting it over several angles, each of which is less sharp than a single one could be, and this is most perfectly done when the rope is bent over the surface of a curve or pulley. If the rope were employed to sustain a fixed body, and not to move a weight, no inconvenience could arise from its rigidity; but when motion is required, it is

necessary that the surface on which it rests should move also, so that the friction is removed in a great degree by the curved surface rolling on with the rope.

When two cords or ropes, suffering the same tension in every part of their length, are parallel, there will be equilibrium of the forces, if each P and P′ is one half of the weight, W; for the arch embraced by the rope being 180 degrees, the chord of which is equal to twice the radius, therefore each of the powers is only one half the resistance, and when one of these chords is fixed, then one power, P, only being in action, it will be in equilibrio and equal to half W. A system of pulleys with four ropes shows the weight to be 16 times the power, upon the same principle; for supposing the first to carry the weight W, and the cord which passes round to have one end fixed at M, and the other attached to the block of the second pulley, and other cords to pass round the various other pulleys in a similar manner; the tension of the first rope is equal to the powers. The first movable pulley sustains a weight equal to twice the power, but the weight which it bears is the tension of the second rope; hence the tension of the second rope is twice that of the first, the tension of the third twice that of the second, and so on. If there be four ropes, the tension of the first is P, the second 2 P, the third 2×2P, or 4 P; that of the fourth $2 \times 2 \times 2$, or 8 P. Each rope added to this system doubles its power, so that $W = 2^n P$, ^{n} expressing the number of distinct ropes there may be applied; or, if ^{n} be the number of movable pulleys employed, there will be an equilibrium when

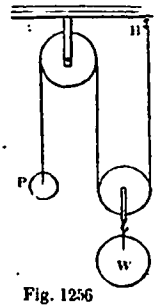


Fig. 1256

$$P : W = 1 : 2^n - 1.$$

To determine the ratio of the power to the resistance when there is an equilibrium with any number of fixed or movable pulleys, and when the cords are parallel.

Spanish Bartons consist of two ropes and two movable pulleys; and by such an arrangement there is a considerable gain of power. The tension of the rope P B is equal to the power, and this rope being finally attached to the pulley, which sustains the weight, supports the part of the weight equal to the power: the rope from A to B balances the united tensions of both parts of the rope, extending from B to the weight and power, and therefore its tension is twice the power; being brought under the pulley which sustains the weight W, and finally attached to the fixed point, it sustains a part of the weight equal to four times the power: thus the whole weight must be equal to five times the power. The rope I passes by F over the wheel A, and it is attached to the wheel B.

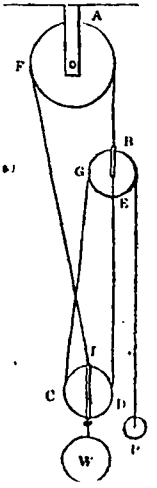


Fig. 1257.

Another system of two ropes is here shown, which does not possess the power of the other: the tension of the rope extending from the power to the fixed point is equal to the power, and the tension of that extending from the pulley A to the weight is obviously equal to twice the power: thus the weight is four times the power. H is the point at which is suspended the rope that passes under the wheel, G C, and over that at A. B is the fixed wheel over which the rope attached to A and E passes: as the wheel A is caused to descend by the power P, so that of G C, to which the weight W is attached, rises.

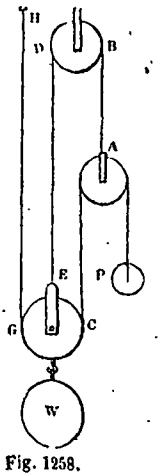


Fig. 1258.

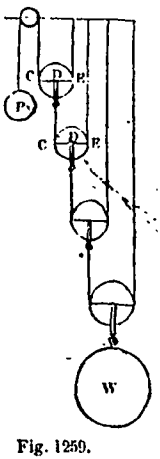


Fig. 1259.

In a system of four ropes the weight is sixteen times the power, for the tension of the rope E C is evidently equal to the power, because it sustains it; D being a movable pulley, must sustain a weight equal to twice the power: but the weight which it sustains is the tension of the second rope; hence the tension of the second rope is twice that of the first: in like manner the tension of the third rope is twice that of the second, and so on, the weight being equal to twice the tension of the last rope. The four ropes, then, of this example have the tension of the first equal to P, of the second equal to 2 P, that of the third 4 P, that of the fourth 8 P, therefore the weight W will be 16 P: each rope so added doubling its effect, and the

condition of such an effect may be thus expressed: $W = 2^n P$, n expressing the number of distinct ropes.

More power may be gained by an arrangement in which each rope is finally attached to the weight. The first rope sustains a part of the weight which is equal to the power: the tension of the second rope is twice that of the first, and therefore sustains a part of the weight equal to twice the power; the third sustains a part equal to four times, and so on, the part sustained by each rope being double that sustained by the preceding one. C is the fixed pulley, B and A are the movable, and the three ropes are attached to the weight W, at D, E, and F.

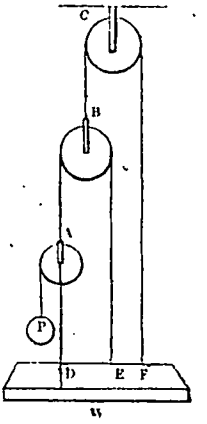


Fig. 1260.

When a rope passes over a single wheel or fixed pulley, as its tension is uniform throughout the length, it follows that in such a case the power and weight are equal; for the latter stretches that portion of the rope which is between the weight and the pulley, while the former stretches that between the power and the pulley: and because the tension throughout the whole length is the same, the weight must be equal to the power; no mechanical advantage is therefore gained from the single pulley, but there are various applications of it where considerable benefit is derived.

In directing the power against the resistance, two fixed pulleys are often found useful; thus, in elevating a weight, the rope may be carried over the pulley at top, and returning downwards, brought by means of another on an horizontal plane or the ground.

A single pulley merely serves to change the direction of motion; that placed on the ground, around which the rope passes, may wind round a windlass, or have the power applied in a horizontal direction, which may be calculated according to the general rule.

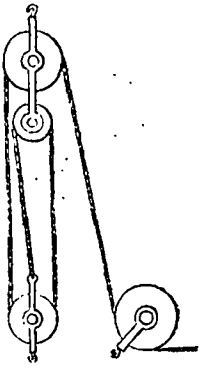


Fig. 1261.

The mechanical power of pulleys admits of being almost indefinitely increased by combination; systems of pulleys may be divided into two classes, those in which a single rope is used, and those which consist of several distinct ropes. In both cases the weight is attached to a movable block, in which are fixed two or more wheels, and whatever the system, every wheel has a separate axle, and there is a distinct wheel for every turn of the rope at each block: each wheel is attended with friction on its axle, and also between the sheave and block, which destroys a great part of the power employed. When the pulley is heavy, and acts in the same direction as the resistance, its weight must be considered as part of that resistance; and if its direction differs from that of gravity, in which the weight of the pulley acts, an allowance must be made for the loss of power. A parallelogram may be drawn to express this, of which one side will represent the weight of the pulley, the other the resistance; its diagonal will then show the real resistance and its direction, which will be greater or less than the other, according as the direction of gravity coincides with or opposes that of the resistance.

Fig. 1262.

Whatever the arrangement of the pulley one law holds good, viz. that as force is diminished, velocity increases, or the power passes over a space greater than that gone over by the weight, by as many times as the weight exceeds the power.

It matters not how these several wheels are arranged; they may be combined in a variety of ways so as to gain an advantage, or as it is termed a *purchase*, which is more or less according to the number of the pulleys, and their mode of combination: the purchase gained is computed by comparing the celerity of the weight raised with that of the moving power, according to the principle of virtual velocities: where the several portions of the cords are parallel to each other, and the weight rises an inch, the blocks will approach each other by that quantity, and consequently the length of cord connecting a single pair of pulleys would be shortened two inches.

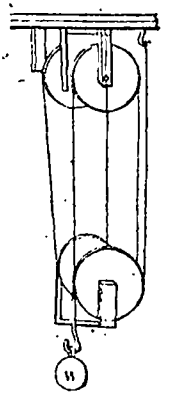


Fig. 1263.

Suppose the pulleys in each block to be n, then while the weight ascends an inch, the power descends $2n$ inches; and consequently, when there is equilibrium, the power is to the weight as 1 to $2n$.

By mariners the case which contains the wheel or sheeve of the pulley is called the block; two or more blocks with the rope constitute a tackle.

When each block contains six sheeves, the ropes are made to pass from one to the other, as expressed in the section, and the power is to be calculated in the ordinary way.

There are many systems of pulleys which are worked by a single rope; in all of this kind there is one movable block in which wheels or sheeves are fixed over which the rope runs, and to which the weight is attached: the weight here is raised by the lower block, and the rope, instead of being finally attached to the fixed block at top, passes over a second wheel in that block, and then under a second in the lower. The weight here is equally distributed among four ropes, each of which is stretched by the force of the power; hence in this case the weight is four times the power.

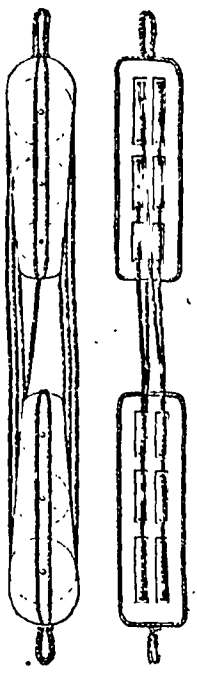


Fig. 1264.

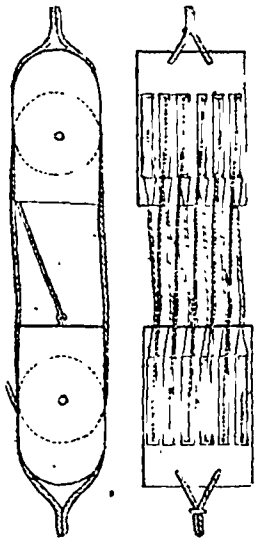


Fig. 1265.

When passed over the third wheel its increase of power may be estimated in a similar manner. M is the fixed point; the weight W is suspended on the sheeve which contains the three lower wheels comprised within R S, as the three upper are between M and N: the rope after passing over A B and under V T, rises to C, and then descends and follows its course, as represented in the former example.

In White's pulley, all the wheels in the same block are reduced to one; or rather, instead of using separate wheels, several grooves are cut round circles of different diameters upon the same wheel: as all circles are proportional to their diameters, it follows that such wheels come under the same law: in the lower block of a pulley so contrived the diameters of the several cylinders are as the odd numbers, 1, 3, 5, 7, 9, &c.; whilst those on the upper block, which is fixed, are as the even ones, 2, 4, 6, 8, &c.: in such an arrangement the universal law of mechanics is followed, viz. that as force is diminished, velocity increases; or, the power must pass over a space greater than that gone over by the weight, by as many times as the weight exceeds the power.

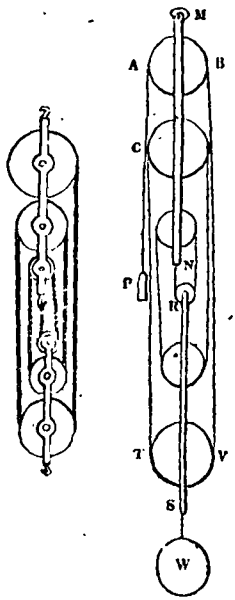


Fig. 1266. Fig. 1267.

Fig. 1268.

White's pulley is so arranged, that the successive wheels revolve in the same time, although they be of different diameters, and are so constructed that their several circum-

ferences are adapted to the length of rope which passed over them at the same time; this will be evident if we consider the circumference of one wheel to be 1 foot, and that it make one revolution while the lower block is raised 1 foot: in this time 3 feet of rope would pass over the circumference of the corresponding wheel; and if the circumference of the latter be 3 feet, it will revolve once during the ascent of the weight: from thence it follows, that the several wheels will revolve in the same time, if their circumferences be as above stated.

In the single movable pulley when the power descends through a space of 2 feet, the rope will have passed over in the same length or be shortened as much; thus the weight ascends through a foot while the power descends 2 feet, or the velocity of the power is twice that of the weight.

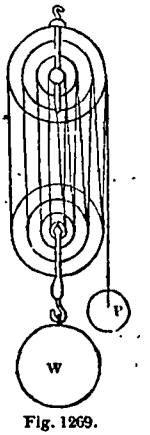


Fig. 1269.

The laws of the equilibrium of pulleys are sometimes supposed to be the same as those which belong to the lever; but this can only be the case where two equal weights suspended by a rope pass over a single pulley: a pulley ought rather to be considered as a cylinder moving on an axis, the sole object being to change the direction of the rope without any unnecessary friction, for when a rope has its course altered by passing over a smooth surface, it communicates to it the entire force which is acting upon it without any friction, and the resistance of such a surface being in a direction perpendicular to itself and to the rope, the force applied remains undisturbed: a fixed pulley, therefore, on this account has no mechanical advantage. By a movable pulley the weight may be suspended by two forces, each equivalent to half the weight applied in a vertical direction to the extremities of the rope; and these forces may be derived from two weights if the rope passes over two fixed pulleys in a proper direction, and if one of the ends be attached to a fixed point, and the other to the weight, the equilibrium will still be maintained.

When two ropes are wound round two cylinders which move on the same axis, there will be an equilibrium when the weights which are suspended to them are inversely as the radii of the cylinders; this will be apparent, if we consider that every section of the cylinder perpendicular to the axis is a circle, and the ropes, being tangents to the circles, will be at the distances of the radii from the vertical plane: therefore by similar triangles the right line joining the weights will be divided in the ratio of the radii, and the centre of gravity will be in the vertical plane; and the point of the axis immediately over it is the centre of suspension. When a rope is wound round a cylinder in contrary directions, the first perpendicular, and the other in an oblique position, there will be an equilibrium when the forces are as the perpendicular distance of any point of the oblique rope from the axis, to its distance from the point of contact.

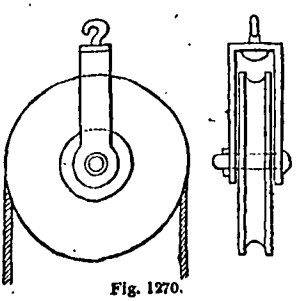


Fig. 1270.

The common pulley consists of a wheel with a groove made on its edge or circumference which confines the rope; this wheel is usually put into an iron frame, where it turns with a metal pin, the diameter of which is about a twelfth that of the wheel; the thickness of the wheel is made a fifth of its diameter.

Sometimes the groove on the wheel is made of portions of cones, so arranged that they hold more securely the rope which is passed over them.

When there is a great strain upon machinery, and its motions are required to be regular, belts and ropes cannot be safely employed, and chains are more advantageous, which act as ropes by simple friction on the surfaces around which they pass. When ropes are used, they generally move in grooves cut in the circumference of the sheaves or wooden wheels.

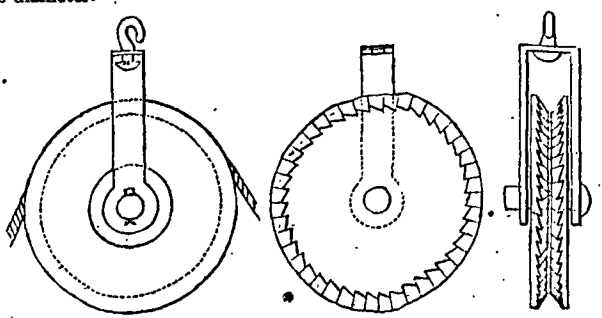


Fig. 1271.

Some pulleys are made to revolve on rollers; the pivot that passes through their centre is made to turn upon two other rollers at each bearing; there are many varieties of friction rollers.

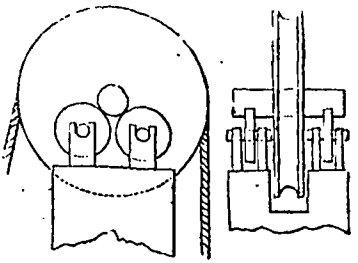


Fig. 1272.

The most efficacious method perhaps of diminishing friction is by the application of friction-wheels: for any friction arising from one body being dragged over another may be changed into that which arises from one body rolling upon another: when the moving force is not exerted in a perpendicular direction, but obliquely, as in the gudgeon of a wheel, it will press with greater force on one part of the socket than on any other.

Some are so mounted that the pulley contains four others that are movable, and which revolve round a fixed cylinder in the middle; the four wheels are retained in their position by two cords which pass over their thickness, and hold them together.

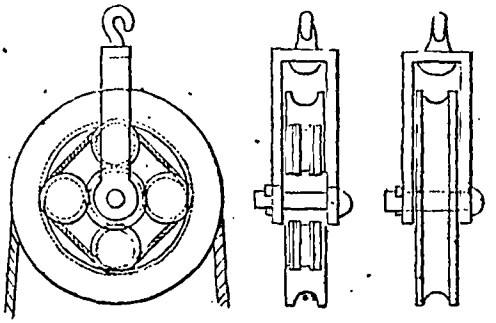


Fig. 1273.

The force of friction, which resists the sliding of different bodies on each other, is closely connected with lateral adhesions; the friction of all solid bodies may be regarded as a uniform retarding force, neither increasing nor diminishing as the velocity of their bodies is changed; when bodies are in contact with each other and at rest, their adhesion is greater than their friction, and this is required to be first overcome.

Sometimes eight small wheels are arranged in a manner to form a regular polygon, being held together by irons which are riveted over their respective centres, the rivet forming the pin upon which they revolve around the fixed centre.

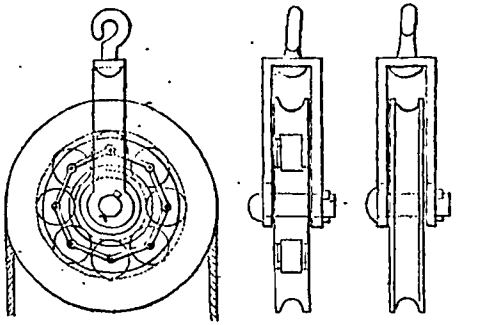


Fig. 1274.

When wheels are fixed on the same pivots, and turn with the same velocity, there is considerable friction and consequently wear, for the rope passing over the wheels with different degrees of velocity, it cannot but slide variously in the different grooves, with the exception of one only. The object then in any arrangement of pulleys ought to be the making them all revolve on their axles at one time, so as to avoid unequal wear, and at the same time their grooves on their exterior should have different velocities, equal to those of the rope which passes over them.

Chains of a variety of forms have been applied instead of ropes to pulleys; that which is commonly used was invented by De Vaucanson, a celebrated mechanic; each chain carries a tooth, which passes into a notch made on the edge of the pulley.

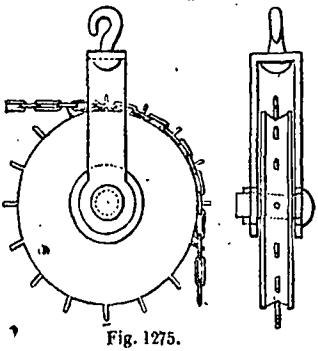


Fig. 1275.

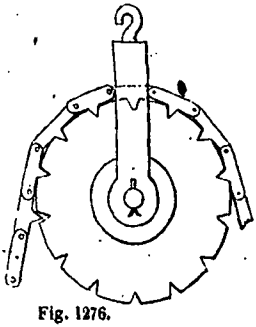


Fig. 1276.

Other pulleys have had the same principle applied, but in a manner

that they can be made to turn only one way, which is serviceable in the raising of weights; the click enters a new notch whenever the pulley moves round, and prevents its receding.

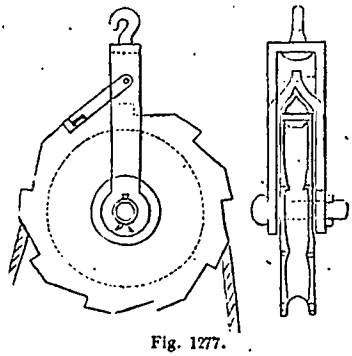


Fig. 1277.

M. Coulomb made several experiments on the simple pulley, where the friction of the axis and the rigidity of the rope produced a joint resistance; when lignum vitæ, moved on iron, was either a fifth or seventh of the weight in all velocities, besides the rigidity of the rope, the mean was a sixth, or with a small weight a trifle more. For axes of iron on copper, where the velocity was small, not quite a twelfth, the friction being always a little less than that on plane surfaces: when the axis was green oak, and the pulley was of lignum vitæ, the friction with tallow was a twenty-sixth, and without it a seventeenth; with a pulley of elm a thirty-third in the first state, and a twentieth in the other: with the axis of box, and the pulley of lignum vitæ, it was a twenty-third and fourteenth: with a pulley of elm, a twenty-ninth and twentieth; and with an axis of iron, and a pulley of lignum vitæ with tallow, it was a twentieth.

There are some which are contrived with a spring at top, which enables the click or ratchet which holds the wheel to be lifted up, so that the pulley may turn in a contrary direction.

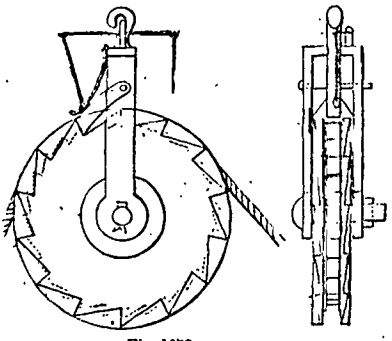


Fig. 1278.

In all these contrivances we must have remembrance that the ropes are subject to considerable rigidity; and this is supposed to vary as the diameter, as the curvature, and as the tension. Coulomb found the power of the diameter expressing the rigidity to be generally 1·7 or 1·8, never less than 1·4, and that a constant quantity must be supposed to be added to the weight. Small wet ropes are more flexible than dry; and when large, less so. Ropes that are tarred are stiffer by about one-sixth, and in cold weather somewhat more; and in general after a little rest, the stiffness of all ropes is increased.

In a rope of three strands each of two yarns, 12¼ lines in circumference, 6 inches of which weighed 2¼ gros, or 125 grains English, being bent on a fixed axis 4 inches in diameter, required a constant force of the tenth of a pound French, and a fifty-fourth of the weight, to overcome the rigidity: the same rope tarred required the fifth of a pound and a fiftieth of the weight. In a rope of five yarns, the circumference 20 lines, and the weight 6¼ gros, the rigidity was equal to half a pound, and a twenty-third of the weight; when tarred, the rope required one pound and one twenty-one parts of the weight to move it. With strands of ten yarns, a circumference of 28 lines, and a weight of 12¼ gros, for 6 inches, the untarred rope showed a rigidity of two pounds and a thirteenth of the weight, and the tarred rope of 2·3 pounds, and a tenth of the weight. These experiments were made on a roller which was allowed to move in a horizontal plane, while the rope was coiled around it; it was therefore necessary to make some allowance for the friction it was liable to, which varied as its weight, and inversely as its diameter.

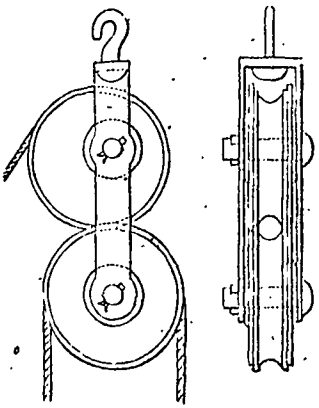


Fig. 1279.

It has been found convenient at times to mount one pulley in such a manner that it has an eccentric motion, which prevents the cord or rope from slipping so easily from off the edge: the pivot upon which the wheel is mounted is placed a little out of the centre, by which means the revolution is changed from that of the regular pulleys, and when the rope attached to it is pulled it presses the eccentric against that which passes over the edge of the lower pulley, and prevents its slipping off.

In a muffle of pulleys, when three are fixed and three movable, there will always be an equilibrium when the weight is to the power, as the number of ropes which bear the lower muffle is to unity: there is the same proportion between the power and the resistance when the pulleys are in different places, or when the fixed pulleys are placed on one axis, and all the movable ones upon another.

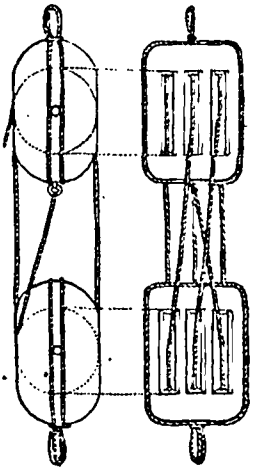


Fig. 1280.

In all movable pulleys whose number is n, when suspended on separate ropes, the extremities of each of which are attached to the weight, there will be an equilibrium when $P : W = 1 : 2^n - 1$. In a combination of pulleys in which two are supported by one rope, there will be an equilibrium when $P : W = 1 : 4$, and all others in the same proportion.

There are several arrangements made in the pulleys used to raise weights: in some single-wheeled pulleys there are means provided to release the rope; a part of the sheeve opens at the edge sufficiently to pass the rope over, or to disengage it: the weight being attached to the movable block, the fixed one serves only to apply the power in the desired direction; the former alone diminishing the power acquired, dividing the weight equally among all the pulleys; every movable pulley requires the application of a force equal to half the weight to produce equilibrium.

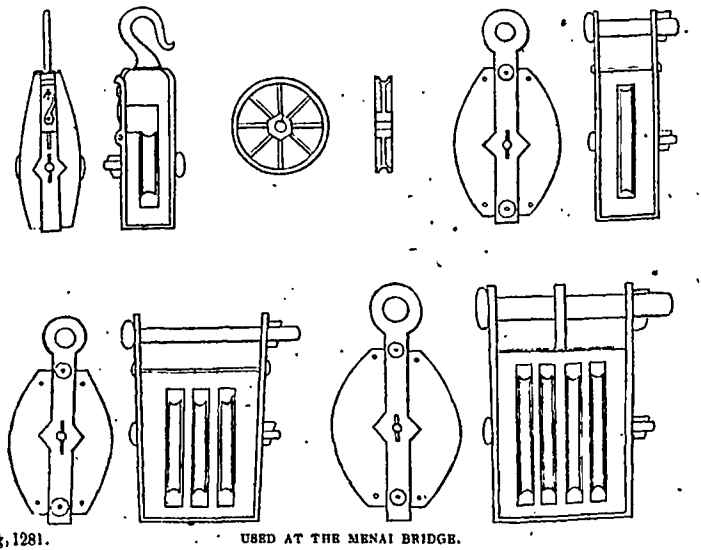


Fig. 1281. USED AT THE MENAI BRIDGE.

The pulley is of great antiquity, and was used by the ancients: we learn from Vitruvius that Ctesibius, whose father was a barber, was born at Alexandria, and that being endowed with extraordinary talent and industry, he acquired great reputation for his mechanical contrivances; wishing to suspend a mirror in his father's shop in such a way that it might be easily lowered and raised by means of a cord, he used the following expedient:—fixing a wooden tube on the under side of the beam he attached a pulley to it, in such a manner that the cord passed and made an angle in descending into the wood which he had hollowed out; there he placed small tubes, within which a leaden ball attached to the cord was made to descend. It happened that the weight in its descent in the tube pressed on the enclosed air, and violently driving out at its mouth the quantity of air compressed in the tubes, produced by its obstruction and contact hollow sounds; this afterwards led to his invention of the organ.

The block or sheeve was much in use by the Romans, and known under the name of *trochlea*, though it was sometimes called *rechamus*. From the description handed down to us by the author above quoted, it would appear that the pulleys were not placed as we have

them, side by side, but under one another; for it is stated that in the *trochlea* are two pulleys turning on an axis; through the upper pulley the drawing rope is passed; then it descends and passes round the under pulley of an inferior trochlea, and returns to the under pulley of the superior trochlea, when it descends to the inferior, and in a hole therein the end of the rope is fixed, the other end of the rope passing to the bottom of the machine. The blocks used in hoisting the various parts of the Menai bridge were of different forms, as shown above, and were admirably suited to their various purposes; they were well proportioned to their works, and the ropes could be taken out easily, as indicated in the single pulley.

Wheel and Axle consists of a cylinder which revolves about its axis, having a wheel of larger diameter affixed to it; the weight is suspended by a cord which is wound round the axle; the power applied acts on the periphery of the wheel. The equilibrium is established when the power is such a multiple of the weight that acts on the axle, as the diameter of the axle is of the diameter of the wheel; thus, if the diameter of the axle be 1 foot, and that of the wheel 10 feet, a power of 1 cwt. will be an equipoise of 10 cwt. or $\frac{1}{2}$ ton: when the power has turned the wheel once round, the axle has revolved once also; the power has gone over a space indicated by the circumference of the wheel, whilst the weight has been raised a height equal to the circumference of the axle.

The wheel and axle bears so strong a resemblance to the lever, that it is not improperly called a continual one; for if two cords perfectly flexible are wound round two cylinders in opposite directions there will be an equilibrium if the drums or rollers are of a similar diameter; and the forces which operate upon any cylinders are universally as their radii, or as their diameters, of which they are the halves: weights in turning round a cylinder exert the same power as the arms or spokes of a lever equal in length to their semi-diameter: the cylinder is often united to a winch or lever; and in this case the radii of the cylinder must be compared with the length of the winch. Let us consider the wheel and axle to consist of a cylindrical axis C D, of any diameter, to which is fixed a wheel A B of a larger diameter, and having its plane perpendicular to the axis, as well as its centre corresponding: the pivots F and D are those on which the axle moves when the wheel is made to revolve.

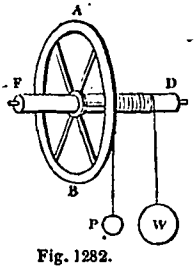


Fig. 1282.

There will be perfect equilibrium when the power is to the weight, as the axle is to the radius of the wheel. Let A B be the axle, O the wheel, W the weight applied to the point E, and let the power P be applied to the point M in the direction M C.

Let O be the centre of the wheel, and K that of the axle; through E draw a plane perpendicular to the axis A B, cutting it at K; therefore the radius K E of the cylinder will be perpendicular to E W: through O draw O F, parallel to K E, and this radius will be horizontal and in the plane of the wheel: let two forces W′, W″, each of which is equal to W, be applied in opposite directions to the point F, and in the vertical line G H, the one W′ acting in the direction F G, and the other W″ in the direction F H. These two opposite forces destroying each other, the equilibrium of the machine is not altered.

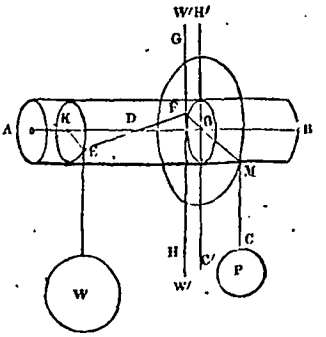


Fig. 1283.

Join F E, meeting in the axis D, and bisecting K O in D; then K E = F O. Let us consider the state of the forces W acting at E, and W′ acting at F. Since W′ = W, the effect of these forces will be the same as 2 W acting on D: but as the point D is in the axis of the cylinder, which axis is immovable, the force 2 W can have no effect in altering the equilibrium or turning the machine round its axis.

The other forces, therefore, are P applied at M, and W″ applied at F, and acting in the direction of F H. We may now consider M O F as a bent lever whose fulcrum is O; and since the forces at M and F, in the direction M C, F H, perpendicular to the arms of the lever, are in equilibrio, these forces will be inversely as the length of the arms, viz. P : W″ = O F . O M; but since F O = E K and W′ = W we have

$$P : W = EK : OM.$$

When, therefore, there is an equilibrium in a wheel and axle, the power is to the weight, as the radius of the axle is to the radius of the wheel.

In the windlass the axle is horizontal, and in the capstan it is vertical, and the advantages gained on the latter application is evident, as it affords the means for a number of workmen

to apply levers or handspikes, and to walk around it without any interruption, the spokes or levers supplying the place of a wheel. When the axle is horizontal, the weight of the machine presses upon the pivots upon which it turns; and when its centre of gravity is equally distant from them, its pressure is distributed equally between them. When, however, the axle is vertical, the whole weight rests upon one pivot, the friction in the two cases varying.

In a machine composed of several wheels and axles connected together by ropes, which pass from the wheel of the one to the axle of the other, the power is to the weight, as the product of the radii of all the axles, is to the product of the radii of all the wheels.

When toothed wheels and pinions are used, the power will always be to the resistance, as the product of the radii of all the pinions, is to the product of the radii of all the wheels.

In all the combinations of the simple mechanical powers, the condition of equilibrium may be easily computed by tracing and calculating the effects of all its separate parts, the effect produced at one part being always considered as the power which is applied to the next part. The relation between power and effect may be found by considering that if the points of the machine to which the power and resistance are applied be made to describe an infinitely small space, the power will be to the weight or resistance as the space described by the point to which the weight or resistance is applied, is to the space described by the point to which the power is applied; then

P = the power,
W = the weight,
p = the space described by the power,
w = the space described by the weight.

We shall then have $P : W = w : p$,

or, what is the same, the power is to the weight, as the velocity of the weight, is to the velocity of the power; consequently whatever is gained in power is lost in time.

Elementary Parts of Machines.—A system of wheelwork is composed of two parts, each turning on a fixed axis: considering two points in this system, the distance of whose axis of rotation is invariable, and supposing a force applied to the first causes it to describe an arc of a circle in any given time, the machine transmits this rotary motion to the second point, which will describe in the same time another arc of a circle. The form of the wheelwork depends on the several positions of the two axes of rotation, and on the relation of the arcs of the same radius described in the same time by two points invariably fixed on these axes. We shall consider the case in which this relation is constant, and determine the form of the wheelwork by two hypotheses, of two parallel axes of rotation of two intersecting axes, and indicate the researches made on the form of wheelwork in the case in which the two axes do not cut.

On Wheelwork having an uniform Rotation round two parallel Axes. — When a point describes a circle, the measure of its absolute velocity is the arc which it describes in an unit of time, the relation of this velocity to the radius of the arc is the measure of its angular velocity. The two parallel axes of rotation being given, draw a plane perpendicular to them, and cutting them in two points as A and d; join these two points by a right line Ad. The relation of the angular velocities of the two fixed points to the parallel axis, Dd and a being known, divide the right line Ad into two parts, A B and Bd touching each other in the point B. Whatever is the force of P applied tangentially to the circle of the radius A B, it is evident that the transmission of the motion of rotation of this first circle to the second Bd will be made by the point of contact B, and that the arcs described in the same time by two determined points of the two circles will be of the same length; whence it follows that the absolute velocities of these two points are equal, but the arcs of the same length and different radii; measure on the circumferences to which they belong angles which are to each other as the inverse ratio of the radii of these circles; whence it follows, that the angular and simultaneous velocities of any two points taken on the circumferences of the radii Bd, A B are to each other in the ratio $\frac{aB}{Bd}$ of these radii.

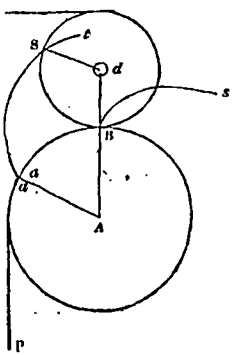


Fig. 1284.

Supposing the axis of rotation A and d, invariably fixed to two given points, and consequently to two circles of the radii A B, Bd: then the rotary motion of these two points will be made in the same time as those of the circles, and the arcs of the same radius, similar to those which they describe simultaneously around the parallel axes A and d, will be to each other in the inverse ratio of the radii A B, Bd. Designating the two given points by M M which turn, the one round the axis A, and the other round the axis d, the

angular velocities of these two points will be in the constant given ratio $(\frac{B\,d}{A\,B})$ of the radii $B\,d$, A B, whatever their absolute velocity may be.

A machine composed only of the two circles A and *d*, which should revolve and touch at the point B would only transmit the motion of the first circle to the second by simple friction at the point of contact, and as soon as the contact should cease, which would happen in a short time, the transmission of motion would no longer take place.

Of the Plane Epicycloid.—When two circles which touch are in the same plane, and one rolls on the other without ceasing to touch, a certain point in the movable circle describes a curve called a plane epicycloid. The movable circle may roll either on the exterior or interior of the fixed one; in the latter case, if the movable circle has a radius of the fixed circle for its diameter the epicycloid would become a right line; this right line is the radius of the fixed circle which passes through, and in which it is touched by the movable circle, considered in its first position.

Let B be the point in which the movable circle in its first position A H K B touches the fixed circle B E F G, in another position A C D; it touches the fixed circle in D, and taking the arc D C of the same length as B D, the point C, the extremity of the arc D C, will be one of the points of the line described through the movable point B of the circle A H K B; further, this point will be on the radius A B. Let us suppose that it is at C; beyond this radius the angle B A D has for its measure either the entire arc B D, or half the arc C D. This arc C D is only half the radius of B D; then in order that it should have twice the number of degrees of the arc B D, it is necessary that the two arcs should be of the same length as D B. Then these two arcs which belong to the same circle are equal, and the points C and C′ are the same; whence it follows that the epicycloid described through the point B of the circle A H K B is reduced to a right line A B.

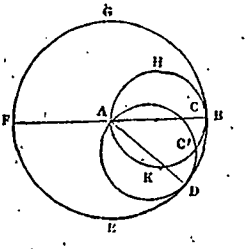


Fig. 1285.

When the movable circle is of infinite radius, it becomes a right line; and the plane epicycloid a development of the fixed circle; if the radius of the fixed circle is infinite, the epicycloid becomes a cycloid.

Roemer, a Danish mathematician, was the first to adopt the epicycloidal curve to the teeth of wheels, in 1674, about which time De Lahire published a work upon the same subject, and demonstrated that if a tooth of either a wheel or pinion be formed by a portion of an exterior epicycloid, described by a generating circle of any dimensions whatever, the tooth of its follower will be properly formed by a portion of an interior epicycloid described by the same generating circle. The object here was to obtain a uniform pressure and velocity throughout the machine, so that the wheels, whatever might be their position, should act uniformly and equally, and that the surfaces of the teeth touching at a point should roll over each other and avoid all friction.

The cycloid and epicycloid have been treated on by numerous writers, and Camus in particular has applied their principles to the forms of the surfaces of the teeth of wheels and pinions acting against each other under different circumstances, as the wheel and trundle, the wheel and pinion, the rack and pinion, conductor or conducted, spur or bevel gear, and others. De Lahire thought the involute of a circle the best of the exterior epicycloids, and considered the generating straight line as a curve of infinite radius, which it is when applied to a pinion acting on a rack.

M. Hachette investigated this question with great ability, and decided the form of curves most applicable to the teeth of wheels: and that the mechanical effect which one wheel produces upon another should be the same in all positions, for which it is necessary that the line perpendicular to the surfaces of the teeth at the point of contact should intersect the line joining the centres at a fixed point that divides the line into two parts, the ratio of which is the mechanical power.

The teeth ought to work a little before and after the line of centres, and some mathematicians have preferred a union of the epicycloid with the hypercloid to effect this more perfectly, as their line of action is nearly perpendicular to the radius, which causes less friction as well as strain upon the axles.

The teeth of wheels have been made so small since the introduction of iron for their manufacture, that their form is not so important; such excellence of workmanship is arrived at, that they are now set out with the template and dividers only. The practical rule made use of by millwrights for finding the depth of the teeth from the bottom to the pitch line, and from thence to the top of the tooth, is simply to multiply the pitch by 5, and divide by 9, and *vice versâ*.

Sometimes the curves of the exterior and interior surfaces of the teeth are set out by a tracer, fixed in the radius line of one of two pieces of board, the edges of which are made to resemble the primitive circles of the wheels: then by fixing a template to one edge, and

dividing the teeth accurately, the tracer will, by the rolling of the two circles, describe the curves sought. The teeth of wheels are usually set out by arcs of circles after their centre and radius are accurately determined.

Iron was first cast into wheels and used in machinery about the year 1782, at the works at Colebrook Dale, though wrought-iron had been partially employed long before on the continent.

When two wheels engage each other the smallest is called the pinion, and the number of their teeth being determined, the line uniting their centres is termed the line of their centres, and if this line be divided in the ratio of the number of teeth in each wheel, this point limits the circle, or what practically is called the pitch line. If from each centre a circle is described, passing through this common point, the diameters of these circles are named primitive or proportional, and the circles themselves the pitch lines; the pitch of the teeth being the distance from each other, as measured across this line as a chord, and not along its circumference. Suppose C D the line of centres, E E the pitch line of the smaller wheel, F F that of the larger, and the centre A to be in the line of centres C D. Let A be the stave of a trundle, from the centre of which describe the arc *b c*, which shows the form of the tooth, which within the pitch line may be drawn circular. The radius for describing the teeth is equal to the pitch, minus half the diameter of the stave of the trundle, and the centres of these arcs will be in the proportional circle, which we have called the pitch line.

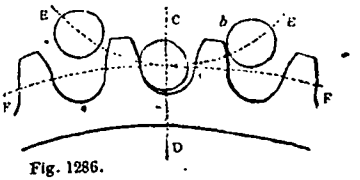


Fig. 1286.

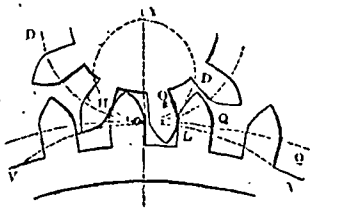


Fig. 1287.

Having set off upon the proportional circles the points G, 2 L, and O o H, according to the thickness of the teeth and leaves, draw lines from these points towards the centre of their respective circles, to serve as the sides of the spaces between the teeth and between the leaves; the depth of which spaces must be such as to give room for the action of the curved part of the teeth and leaves. Then describe upon the extremity of the sides of each tooth epicycloids, such as Q D, L D, with the generating circle Y, the diameter of which is equal to the proportional radius of the pinion, upon the circumference of the proportional circle of the wheel as a base.

The mode of forming the teeth being shown, that of the leaves will be obvious, V V being the generating circle of the epicycloid upon the circumference of the circle of the proportional pinion as a base. When the teeth are small, and do not begin to act till they arrive at the line of the centres, the teeth of the wheel when the wheel drives the pinion, or the leaves of the pinion when the pinion drives the wheel, may be described by a circular arc, of which the radius is equal to the pitch, and of which the centre is in the pitch line of the wheel or pinion.

Another method is shown, which may be considered more simple:—

Let A A represent the pitch ine, the circle B B the bottom of the teeth, and D D the top.

After the pitch line is described, it is divided into the number of teeth the wheel is to have; with a radius equal to one and a quarter of these divisions, strike circles upon the pitch line A; thus the curved part of each side of the cog is formed. The remaining portion of the tooth within the pitch line A is bounded by two straight lines, drawn from the point *g m n* towards the centre of the wheel; the spaces between, as well as the teeth, are all equal.

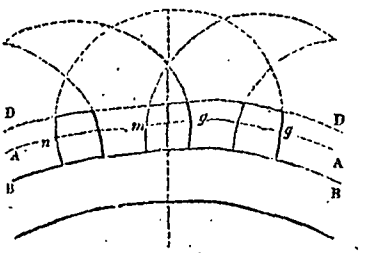


Fig. 1288

Another method may be shown, which requires, however, to be executed with attention. Let the tooth G C H have the form of a curve traced by the extremity of a thread F C, unlapped from the circumference, and let the acting face of the tooth *b* be formed in a similar manner: then the line F C E, drawn perpendicularly to the touching point C, is in the direction of the threads, by which the two acting faces are formed; this line, being the common tangent to the circumferences of the two wheels, will always cut the line A B in the point D: thus the teeth can act on each other at the same time, and the pressure is spread over a number, instead of being confined to one.

When a wheel and pinion act with each other, the teeth of the small wheel may be made to represent the staves of a trundle; suppose the teeth divided on the pitch lines E E, F F: on the wheel C form circles, which may represent staves; the centre of one of these staves or teeth being placed on the line of centres at A, draw the line A B, uniting the centres of these teeth.

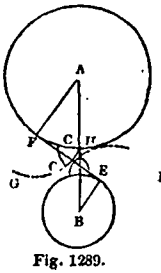


Fig. 1289.

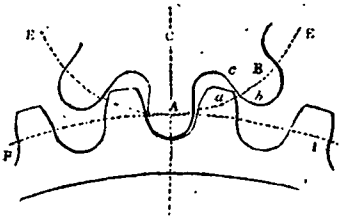


Fig. 1290.

Then the radius A *b* from A as a centre will describe *bc*, the curve of the tooth of the conducting wheel, and the curve *ba* that of the other wheel. Radius being equal to pitch, diminished by half the diameter of the circle of the stave teeth, and as the centres will always be in the pitch lines, the other teeth may be easily drawn.

Bevelled Gear, or conical wheels, are usually frustra of fluted cones; the axis or shaft of the leader or driver is placed at an angle of 45 degrees with the axis of the shaft of the follower or driver. To form a pair of conical wheels there must be set out on the frustra regular series of teeth at equal distances, projecting as much above the surface as the hollow between them descends. These teeth must be directed towards the apex, so that when they are in contact, they shall touch each other along the whole length; when the point of contact is along the line of centres, there is little or no friction. Wheels of this kind are used to communicate motion in any direction that is required, and the action of the teeth is the same as in the common spur-wheels; the diminution of the teeth being in the same ratio in both cases, but requiring more attention in the setting out than the common teeth.

Supposing it is required to determine the diameter of two wheels that shall change a motion into a direction of the angle above mentioned, and in which the axle shall move with four times the velocity; the wheel mounted on the axis that is to revolve four times more rapidly, must have one-fourth the number of teeth, and one-fourth the diameter.

Let the cone A C D have its slant height at right angles to C B D; the cone will then intersect the teeth at right angles.

If A B show the original direction of the motion to be changed, through the point O draw C O D at an angle of 45 degrees to the line A B. The axle C D is required to move four times more rapidly than A B; the wheel which it carries must have only one-fourth the number of teeth. Draw *cd* at any distance parallel to C D, and *ab* parallel to A B, so that $Aa = Bb = 4Cc = 4Dd$, and join the points of intersection *i* in O: draw O *m*, so that the angle B O *m* equals B O *i*, and O *n*, so that D O *n* equals D O *i*, and these lines show the size and position of the cones of which the wheels are to be formed. The angle B O D is in fact divided into two angles, whose sines are to one another as the number of revolutions of one wheel is to the number of revolutions of the other.

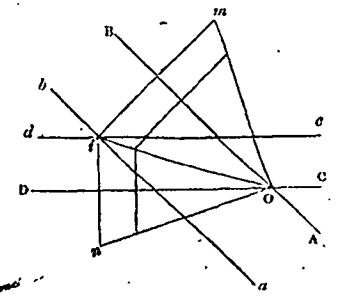


Fig. 1291.

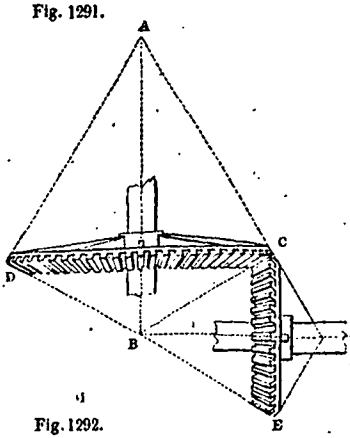


Fig. 1292.

The surface of the cone may be developed on a plane by rolling it round its apex, and by this means the true impression of its teeth taken; the pitch circumference of C D will be the sector of a circle, the slant height B C being radius.

The wheel and pinion may be either situated on the same plane, or their planes may form an angle, in which case one of them becomes the crown wheel, or both of them may be bevelled, and their teeth cut obliquely: according to the relative magnitude of the wheels, the angle of the bevel must be different, in order that their velocities may be in the same proportion at both ends of their oblique faces; for which purpose, it becomes necessary that the teeth must be directed to the point where the axes would meet. Some mechanics have considered that the angles should be as the diameters of the wheel,

for in reality the tangent of the angle must be to the radius as one diameter to the other. Hence we see that the bevel of the wheels must be such, if we suppose their shafts produced, till they meet a line drawn from that point to the meeting of the circumference of the wheels will determine the angle or bevel of their edges, so that they will work freely and equally together. When the acting faces of the teeth on the large wheel have the form of a spherical epicycloid, whose generating circle is the primitive circumference of the pinion, and whose base is the primitive circumference of the wheel, and if they drive the smaller wheel by acting upon infinitely small pins in its circumference, the motion of both will be found uniform. If the acting faces of the teeth of the large wheel have the form of spherical epicycloids, whose generating arch has a radius equal to half the primitive radius of the smaller wheel, and whose base is the primitive circumference of the wheel, and if they drive the small wheel or pinion by acting upon rectilineal leaves directed to its centre, the motion will be uniform. If a bevelled wheel drives a conical lantern with conical spindles, it will be done uniformly, when the acting faces of the teeth of the bevelled wheel have the form of a curve drawn parallel to the spherical epicycloid and distant from it by the radius of the spindle.

Strength of the teeth of wheels may be calculated upon the principle of a beam fixed at one end, and sustaining pressure at the other; when the pressure at the pitch line is given, multiply it by the length in inches of the tooth to this line, and divide the product by 2544 times the square of the thickness, and the quotient will be the breadth in inches; it is usual in practice to make the breadth of the wheel and teeth two or three times the pitch of the teeth.

The table gives the radii of wheels, the pitch being an inch, and the teeth of various numbers. When it is required to find the radius for any other pitch, it is only necessary to multiply the number in the tables by the proposed pitch of the wheel, and the product will be the primitive or proportionate radius, viz. the radius measured from the centre to the pitch line.

The table is founded upon the following principles: divide 360 degrees by twice the number of teeth, and it will give half the angle the pitch subtends at the centre, and the cosecant of this angle to a radius equal to half the pitch is the radius sought, thus:—

$$\text{Primitive radius equal to half } p \times \text{cosecant } \frac{180^\circ}{\text{number of teeth}}.$$

To determine the diameter of any wheel where the pitch and number of teeth are given, it is only necessary to multiply the number of the teeth by the pitch, and divide this product by 3·1416.

	0	1	2	3	4	5	6	7	8	9
10	1·668	1·774	1·932	2·089	2·247	2·405	2·563	2·721	2·879	3·038
20	3·196	3·355	3·513	3·672	3·830	3·989	4·148	4·307	4·465	4·624
30	4·783	4·942	5·101	5·260	5·419	5·578	5·737	5·896	6·055	6·214
40	6·373	6·532	6·643	6·850	7·009	7·168	7·327	7·486	7·695	7·804
50	7·963	8·122	8·231	8·440	8·599	8·753	8·962	9·076	9·235	9·399
60	9·553	9·712	9·872	10·031	10·190	10·349	10·508	10·662	10·826	10·935
70	11·144	11·303	11·463	11·622	11·731	11·940	12·099	12·758	12·417	12·676
80	12·735	12·895	13·054	13·213	13·370	13·531	13·690	13·849	14·008	14·168
90	14·327	14·436	14·645	14·804	14·963	15·122	15·281	15·441	15·600	15·759
100	15·918	16·072	16·236	16·395	16·554	16·713	16·873	17·032	17·191	17·350
110	17·504	17·668	17·987	17·827	18·146	18·305	18·464	18·623	18·782	18·941
120	19·101	19·260	19·419	19·578	19·737	19·896	20·055	20·214	20·374	20·533
130	20·692	20·851	21·010	21·169	21·328	21·488	21·647	21·806	21·460	22·124
140	22·283	22·442	22·602	22·761	22·920	23·074	23·288	23·397	23·556	23·716
150	23·875	24·034	24·193	24·352	24·511	24·620	24·830	24·989	25·148	25·307
160	25·466	25·625	25·784	25·944	26·103	26·262	26·421	26·580	26·739	26·894
170	27·058	27·217	27·376	27·535	27·694	27·853	27·931	28·172	28·331	28·490
180	28·699	28·808	28·967	29·126	29·286	29·445	29·604	29·763	29·922	30·086
190	30·241	30·400	30·559	30·718	30·877	31·036	31·196	31 355	31·514	31·673
200	31·832	31·992	32·150	32·310	32·469	32·628	32·787	32·846	33·105	33·264
210	33·424	33·583	33·742	33·901	34·060	34·219	34·278	34·537	34·697	34·856
220	35·015	35·174	35·333	35·492	35·652	35·811	35·970	36·129	36·288	36·447
230	36·607	36·766	36 925	37·084	37·243	37·402	37·561	37·720	37·880	38·039
240	38·198	38·357	38·516	38·725	38·835	38·994	39·153	39·312	39·471	39·631
250	39·790	39·949	40·108	40·262	40·426	40·585	40·744	40·904	41·063	41·222
260	41·381	41·541	41·699	41·858	42·019	42·177	42·336	42·495	42·654	42·813
270	42·973	43·132	43·291	43·450	43·609	43·768	43·927	44·087	44·231	44·405
280	44·564	44·723	44·882	45·042	45·201	45·360	45·519	45·678	45·837	45·996
290	46·156	46·315	46·474	46·633	46·792	46·751	47·111	47·270	47·429	47·588

In the foregoing table, supposing it is required to find the radius of a wheel having 105 teeth, look for 100 in the first column, and under 5 in the top, we find 16·713, and supposing the pitch to be more than one inch, we multiply this number found by the pitch in inches. For a greater number of teeth than is given in the table, take half the given number, and double the quantity in the columns, and for any less number, the general rule may be applied.

The following table contains the pitch and dimensions of teeth of wheels already executed, and satisfactorily performing their work, with their power and velocity per second.

Pitch of Teeth in Inches.	Thickness of Teeth in Inches.	Breadth of Teeth in Inches.	Length of Teeth in Inches.	Horse-power at 2·27 Feet per Second.	Horse-power at 3 Feet per Second.	Horse-power at 6 Feet per Second.	Horse-power at 11 Feet per Second.
4·2	2·	8·	2·40	13·33	17·61	35·23	64·6
3·99	1·9	7·6	2·28	13·03	15·90	31·80	58·30
3·78	1·8	7·2	2·16	10·80	14·27	28·54	52·32
3·57	1·7	6·8	2·04	9·63	12·72	25·54	46·68
3·36	1·6	6·4	1·92	8·53	11·27	22·54	41·32
3·15	1·5	6·	1·80	7·50	9·91	19·82	36·33
2·94	1·4	5·6	1·68	6·53	8·63	17·26	31·64
2·73	1·3	5·2	1·56	5·63	7·44	14·88	27·28
2·52	1·2	4·8	1·44	4·80	6·34	12·68	23·22
2·31	1·1	4·4	1·32	4·03	5·32	10·64	19·54
2·10	1·	4·	1·20	3·33	4·40	8·81	16·15
1·89	·9	3·6	1·08	2·70	3·57	7·14	13·09
1·68	·8	3·2	·96	2·13	2·81	5·62	10·33
1·47	·7	2·8	·84	1·63	2·15	4·30	7·88
1·26	·6	2·4	·72	1·20	1·59	3·18	5·83
1·05	·5	2·	·60	·83	1·10	2·20	4·03

The thickness of the teeth, as given in the second column, varies one-tenth of an inch in each line; and it must be further observed that the breadth of the teeth is always four times as much as their thickness. The strength of the teeth is ascertained by multiplying the square of their thickness into their breadth taken in inches and tenths. The pitch is found by multiplying the thickness of the teeth by 2·1.

Construction of Wheels.—When of wood, they are usually formed of three thicknesses, and the joints broke over each other; the middle thickness is made in six or eight pieces: a solid rim is formed by bolting them together; this is mortised for the cogs, the tenons of which have a pin driven through to hold them in their place. The arms are mortised sometimes through the shafts, but which weakens them, and is not the best manner; they may be halved into each other, and form a frame with a square opening in the centre; the arms may be secured to the middle thickness of the rim by bolting them well together.

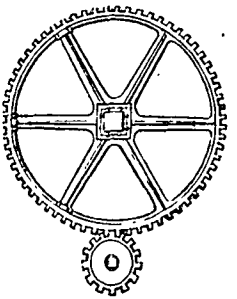


Fig. 1293.

A wheel of this kind may be easily attached or removed to the shaft by the adjustment of wedges, which are inserted around the shaft, and which close up the square hole left in the framing.

Face Wheels have stays and braces attached to the back of the rim, some distance along the shaft into which they are mortised, in order that greater strength may be obtained: this is necessary, as the face wheel, when acting with a trundle, has its teeth thrown off, and requires a stay to prevent it. The trundles usually are surrounded with iron, to prevent them from splitting, and small pinions are made out of a solid block of wood, with the cogs fitted into it.

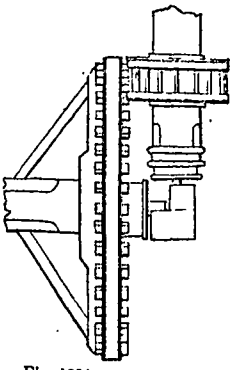


Fig. 1294.

Iron wheels are more usually adopted, and have their teeth cast with them, or mortices left for the insertion of wooden cogs: it has been found that wheels work with less noise and friction when wooden and iron cogs are used together. When this practice is adopted, the thickness to be given to the wooden cogs must be a little more than the space between them; and the space in the wheel corresponding to it must be made a little more than its teeth. The iron teeth generally given to the smaller wheel are chipped with a cold chisel;

hammered, and afterwards filed into the true form: when iron wheels are under ten feet in diameter, they are cast entire; when larger, the arms are cast in separate pieces, and they are attached to the rims by flanches, and securely bolted together: these flanches should be cast at right angles to the circumference, and the arms are secured to the boss by means of two projecting pieces cast upon it, and which fit into the nave or boss.

In the construction of fly-wheels the greatest quantity of cast-iron possible is given to the rim and arms, in order that the momentum generated in the rim should not destroy it: they are usually cast in a number of pieces, and bolted together, using every means to resist the tendency they have to fracture.

Strength of Wheels.—We must first ascertain the weight which acts on the rim of the wheel, then the length of the arm or lever, and the part supported by each arm, must be taken as a fraction of the whole. Suppose, then,—

w = the weight, or straining power in pounds.
r = the radius in feet.
b and d = the breadth and depth of the arms in inches.
n = the number of arms.
a = the quantity of allowable deflection.

$$\frac{w\,r^3}{2656\,n\,a} = b\,d^3.$$

The breadth or depth being given, the other dimensions may be found:—in a wheel 6 feet radius the number of arms eight, the weight acting on its circumference 1600 pounds, and the allowed deflection a tenth of an inch: then—

$$bd^3 = \frac{1600 \times 6^3}{2656 \times 8 \times 1} = 163.$$

Hence when the breadth is $2\frac{1}{2}$ inches, then—

$$d = \sqrt[3]{\frac{163}{2{\cdot}5}} = 4{\cdot}03 \text{ inches in depth.}$$

When a wheel is so strained that the arms break, the fracture takes place near the axle, and here then should the greatest strength be given.

Shafts or Axles are employed either in a horizontal or vertical position, and the arbour or spindle on which they turn is called a gudgeon. A horizontal shaft has a support between the first mover and the work to be performed; the cylindrical portion revolving on this support is called the journal; that which supports it, or in which the journal revolves, is called the carriage, but when it is not a part of the framework, it is called a plummer's block; the lower gudgeons of upright shafts rest upon steps or bearings.

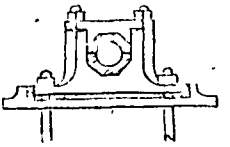


Fig. 1295.

When shafts are made of cast-iron, their strength may be thus calculated; suppose r = to the radius of the wheel in feet, at the circumference of which the power is applied, s = to the side of a square, or d = to the diameter of the shaft in inches, t = to the thickness of the metal in a hollow cylinder, w = to the weight in pounds. In cast-iron shafts,

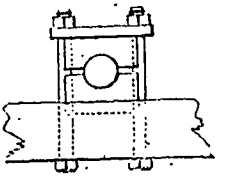


Fig. 1296.

Square	$r\,w = 150\,s^3$
Solid cylindrical	$r\,w = 125\,d^3$
Hollow cylindrical	$r\,w = 125\,d^3\,(1-p^4)$

In wrought-iron shafts,

Square	$r\,w = 168\,s^3$
Solid cylindrical	$r\,w = 140\,d^3$
Hollow cylindrical	$r\,w = 140\,d^3\,(1-p^4)$

Where $p = \dfrac{d-2t}{d}$,

then for cast-iron shafts, where the length does not exceed one-fourth of e, we have

$$S = \sqrt[3]{\frac{r \times w}{150}} \text{ for a square shaft,}$$

$$d = \sqrt[3]{\frac{r \times w}{125}} \text{ for a solid cylinder,}$$

$$d = \sqrt[3]{\frac{r \times w}{125\,(1-p^4)}} \text{ for a hollow cylinder.}$$

The same formula answers for malleable iron, if we use the number 168 for the first, 140 for the second, and 140 $(1-p^4)$ for the third divisors: when the shafts are cylindrical and of cast-iron of great length, multiply the weight in pounds by r in feet, and divide the product by the cube of the length in feet, multiplied by 5·2; add 5148 to the quotient,

extract the square root, and subtract 72; then multiply by the square of the length in feet, and the result will be d, or the diameter in inches.

The lateral strain and twisting to which shafts are subjected must be estimated, and it commonly happens that one of these forces exceeds the other, and therefore the greater power is the one to provide against; the resistance to a lateral strain is measured by its resistance to resist flexure, and which may be about one-hundredth part of an inch for each foot in length, before it materially affects the regularity of the motion of the machine.

For the lateral stress on cast-iron shafts, the weight w in pounds, acting in the middle of the length l in feet,

$$\sqrt[3]{\frac{w \times l}{500}} = d.$$

For malleable iron the result must be multiplied by 0·935, for oak 1·83, for fir 1·72, and for shafts to resist torsion, we have in horse-power h, that the shaft will drive, making n turns per minute,

$$\sqrt[3]{\frac{240 \times h}{n}} = d \text{ for cast-iron.}$$

For malleable iron multiply the result by 0·963, for oak by 2·238, and for fir 2·06; these are for shafts of first movers, for second movers multiply the first by 0·8, and for third by 0·793. To show the application of the preceding rule, suppose the length of a shaft, from the water-wheel to the cogwheel, to be 6 feet, the radius of the water-wheel 9 feet, and the greatest force it will be exposed to 2000 pounds.

$$\frac{9 \times 2000}{5 \cdot 2 \times 6^3} = 16 \text{ nearly.}$$

$$\sqrt{16 + 5184} = 72 \cdot 12$$

subtract 72

$\cdot 12$: then $\cdot 12 \times 6^3 = 4 \cdot 32$ inches.

Practical men usually estimate the size of shafts or journals by the number of horse-powers, and the speed of the fly-wheels.

Rightly to proportion the shafts of mills to the stress they are subjected to is of great practical importance; timber formerly was entirely used for the axles of mills, and since the application of iron to this purpose, machinery has undergone an entire change. Tables giving the proportions have been established, so that now the mechanic is guided with greater certainty in his work. It must always be borne in mind that the *stiffness* of a shaft or beam is the property it has to resist bending or flexure, and that *strength* is that which resists breaking or fracture: the stiffness, then, is determined by the force which causes it to recede, its transverse strength by the *pressure* required to break it.

This distinction is expressed when we say that beams of equal length have their lateral *stiffness* as the breadth and cube of their depth, and their lateral strength as the breadth and square of the depth.

Lateral stress, which produces fracture, or which tends to break a body across, is proportional to the rectangle of the parts of the beam, and is the greatest when loaded in the middle; the rectangle being the product of the parts multiplied into each other. When a shaft is loaded exactly in the middle, half the weight is borne on each end, but we may generally consider the weight which is spread over any part of a beam as united in its centre of gravity.

When timber is submitted to a transverse strain, the effect of the weight is greatest in a certain and determinate point, where if sound, defects in other portions are not so important; but if placed in a position to receive pressure endwise, the defective parts at once come under its influence; hence it is of the utmost importance in making experiments upon the strength of materials, that they should be subjected to every species of trial previously to their application to the purposes of construction, or to machinery of any kind. In the Philosophical Transactions for 1818, Mr. George Rennie describes the apparatus he used in his experiments relating to *torsion*: it consisted of a wrought-iron lever 2 feet long, having an arched head of about 60°, and 4 feet in diameter, of which the lever represented the radius; in the centre, round which it moved, was a square hole to receive the end of the bar to be twisted: the lever was balanced, and a scale hung on the arched head, the other end of the bar being fixed in the square hole in a piece of iron, and that again in a vice.

Cylindrical shafts of cast-iron, having the stress applied to them in the middle, and equal to W hundred-weights, and the flexure not exceeding as many hundred parts of an inch as the shaft is long in feet, then the fourth root of half the stress in hundred weights, multiplied by the square root of the length in feet, gives the diameter in inches, and it has been found, that when the cube of the length in feet is multiplied by ·007, the square root of the product will be the diameter in inches.

Shafts of Cast-Iron to resist Lateral Pressure.

Length in Feet.	Diameter in Inches.	Diameter in Inches.	Diameter in Inches.	Diameter in Inches.	Diameter in Inches.
2	·237	·31	·44	·54	·62
4	·67	·88	1·24	1·5	1·76
6	1·23	1·61	2·28	2·79	3·22
8	1·9	2·48	3·51	4·30	4·96
10	2·65	3·47	4·9	6·0	6·93
12	3·48	4·55	6·44	7·89	9·10
14	4·38	5·74	8·12	9·94	11·48
16	5·36	7·01	9·92	12·15	14·02
	Own weight only.	Stress equal to its own weight, or n = 1.	Stress double its own weight, or n = 2.	Stress three times its own weight, or n = 3.	Stress four times its own weight, or n = 4.

When shafts of cast-iron are hollow, they will resist more twisting than solid ones containing the same quantity of metal, for circles are to each other as the squares of their diameters, and to compute the diameters of a hollow cylindrical shaft, where the thickness of the metal is two-tenths of the entire diameter, which is found to be usually adopted in practice; the cube of the length in feet, multiplied by ·009, and the product again multiplied by the number of times the weight of the shaft is contained in the stress; from the latter product extract the square root, which will be the diameter in inches. It has been found that the square of the exterior diameter in inches, multiplied by 1·6 times the length in feet, gives nearly the weight of the shaft in pounds.

Hollow Shafts of Cast-Iron to resist lateral Stress, though it is necessary to consider Torsion as well.

Length.	Exterior Diameter in Inches.	Interior Diameter in Inches.	Exterior Diameter in Inches.	Interior Diameter in Inches.	Exterior Diameter in Inches.	Interior Diameter in Inches.	Exterior Diameter in Inches.	Interior Diameter in Inches.
4	1·5	0·9	1·9	1·1	2·2	1 3	2·4	1·4
6	2·8	1·6	3·5	2·1	4·0	2·4	4·5	2·7
8	4·3	2·5	5·3	3·1	6·1	3·6	6·9	4·1
10	6·0	3·6	7·4	4·4	8·5	5·0	9·5	5·7
12	7·9	4·7	9·8	5·8	11·2	6·7	12 6	7·5
14	10·0	6·0	12·3	7·3	14·2	8·5	15·9	9·5
16	12·2	7·3	15·0	9·0	17·3	10·3	19·4	11·6
	Stress four times the weight of the shaft.		Stress six times the weight of the shaft.		Stress eight times the weight of the shaft.		Stress ten times the weight of the shaft.	

When the diameter of a shaft is found for cast-iron, by multiplying this diameter by ·935, the product will give a diameter for a shaft of equal stiffness made of wrought-iron; and a shaft of fir should be 1·716 times the diameter of a cast-iron one, and of oak 1·83 times, in order to be of equal stiffness.

Shafts of cast-iron to resist torsion may have their diameter, when cylindrical, according to the following table, which is found by dividing 240 times the number of horse-power by the number of revolutions per minute, and extracting the cube root of the quotient for the diameter in inches.

Revolutions of the Shafts in a Minute.

Diameter of Shafts in Inches.	5	10	20	30	40	50
	Horse-power.	Horse-power.	Horse-power.	Horse-power.	Horse-power.	Horse-power.
2	0·17	0·33	0·66	0·99	1·33	1·66
3	0·56	1·13	2·25	3·37	4·5	5·62
4	1·33	2·66	5·33	7·99	10·66	13·33
5	2·6	5·2	10·4	15·6	20·8	26·0
6	4·5	9 0	18·00	27·0	36·0	45·0
7	7·15	14·3	28·6	42·9	57·2	71·5
8	10·66	21·33	42·66	64·0	85·0	106·6
10	20·83	41·66	83·33	125·0	166·0	208·3
12	36·00	72·0	144·0	216·0	288·0	360·0
14	63·83	127·66	255·33	383·0	510·0	638·3
16	85·33	170·66	341·33	512·0	682·0	853·3

When the cylindrical shafts are hollow, the diameter must be multiplied by 1·05, and when the shafts are laid horizontally, something should be added to what is given in the foregoing tables, as they are calculated for vertical shafts.

When the shaft is of wrought-iron, multiply the diameter found by 0·963, if of oak by 2·238, when of fir by 2·06.

In the following table is given the dimensions of several shafts, subject to torsion and lateral pressure, and which have been found to work well in practice.

	Horse-power.	Revolutions per Minute.	Diameter of Journals in Inches.	Length of Shaft.	Section of the Middle.	Diameters of Journals.
Cast-iron lying shaft	20	20	6	11	7¾	7·368
—	18	22	5¾	11	7	6·889
—	16	22	5½	10·6	7	6·621
—	14	24	5	10	6¾	6·153
—	12	25	5	9·6	6	5·768
—	10	25	4¾	9	6¾	5·428
—	8	27	4	9	6	4·904
—	6	28	4¼	8·6	5¾	4·414
—	5	30	3⅞	8·6	5¼	4·061
—	4	32	3¾	8	4¾	3·484
—	3	34	3¼	8	4	1·203
—	2	36	2¾	8	3	2·802
—	1	40	2	8	3¼	2·154
Malleable iron lying shaft	6	28	3	8·6		
—	5	30	3¼	8		
—	4	32	2	8		
—	3	34	2	8		
—	2	36	1¾	8		
—	1	40	1	7·6		

The cross-tailed gudgeon, which is made of cast-iron, must be turned very true; it consists of four leaves, which form a cross, and which are let into the end of a wooden shaft; the front edge of each leaf is made thinner than the back, so that when it is inserted, and a pair of strong hoops are driven tight upon the end of the shaft, the wood is closed all round the cross and holds it fast: screws are occasionally added to secure the cross.

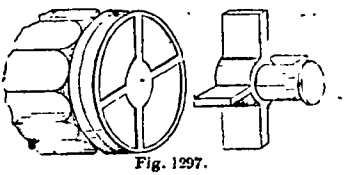


Fig. 1297.

An octangular wooden shaft is generally used for a water-wheel, made of a sufficient length to reach across the pit in which the wheel works; the gudgeon at each end supports it, and allows it to revolve upon its proper bearings. A cast-iron box in this case is fitted upon the end of the shaft and tightly wedged; this prevents the shaft from splitting as effectually as hooping. Upon the end of this iron box is a projecting flanch, on the face of which are four grooves or notches, into which the arms of the iron cross enter; this is also part of the gudgeon on which the shaft revolves.

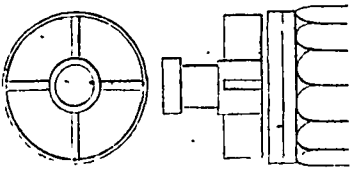


Fig. 1298.

The best shape for cast-iron shafts is tubular or hollow cylindrical; and care should be taken that at each extremity the metal should be thicker; the gudgeon should have three arms cast or wrought on it, so that it can be attached to the end of the shaft by screws or bolts.

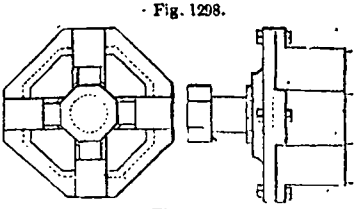


Fig. 1299.

The end of the wooden shaft is sometimes fitted into a cross piece and box, for the purpose of more readily putting on a new gudgeon when required; by simply taking out the screw-bolts this is easily performed.

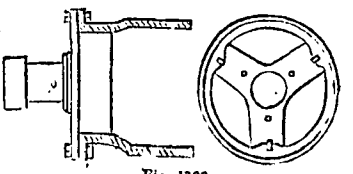


Fig. 1300.

The strength of a gudgeon is limited by the strain it will bear, and the calculated stress should include every kind of force acting on the shaft; the diameter should always be determined, so that the gudgeon may be capable of resisting the whole if occasion required. If w represents the stress upon the gudgeon in hundred weights, and l its length in inches, then $\frac{(112\,w \times \frac{1}{12}\,l)^{\frac{1}{2}}}{5}$ $= \text{or } 0{\cdot}42(w\,l)^{\frac{1}{2}} = d$, the diameter of the gudgeon in inches.

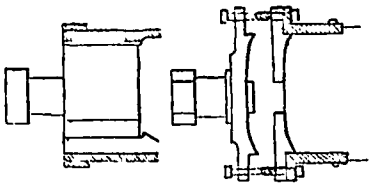


Fig. 1301.

Journals are those parts of a shaft which revolve between the points where the power and resistance are applied, and these have sometimes to carry a fly-wheel, as well as to resist great torsion; to proportion the stress they have to sustain, we must consider the horses-power to which the resistance is equal *directly*, and the number of revolutions the shaft makes inversely.

Gudgeons are the ends or extremities of a horizontal shaft which runs in the collar, and in order to avoid friction, are usually made of a diameter as small as possible, so that their strength is sufficient. The cube root of the weight of a water-wheel in hundred weights is found to be nearly equal to the diameter in inches of a cast-iron gudgeon sufficiently strong to support it: gudgeons of cast and wrought-iron are in the proportions of 9 to 14; the diameters of journals or gudgeons, when of one or the other, serve, when determined upon, in some degree to proportion the shaft. The axis of the gudgeon should always be in the line with the axis of the shaft, in order that the motion should be uniform and regular: when the water-wheels are formed of timber, their diameter in feet must be multiplied by the width in feet, and to this product the square of half the diameter must be added. The diameter of the gudgeon in inches will be the cube root of this sum.

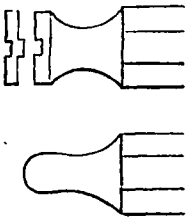


Fig. 1302.

Gudgeons when applied to water-wheels, spindles to grindstones or to other wheels, may be all calculated upon the above principles.

Couplings may be considered to have either one or two bearings, and serve for the conveyance of motion by connecting a series of shafts. The square coupling box is the most simple, and is formed by making it exactly of the dimensions of the ends of the shaft it is to contain, so that when motion is given to one shaft it may convey it to the other; it should also be so contrived that it may be slipped over one shaft, and the other be disengaged, by which means the motion may be discontinued. The square coupling box is now only generally employed in small machines, and has given way to a cylindrical one, in which pins at right angles are inserted through them into the shaft to hold them firmly together; these may be turned with great accuracy, and are found to get out of order less often than the square coupling.

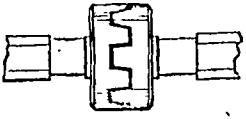


Fig. 1303.

When a shaft has two bearings, the common coupling used is that here shown: the shafts are terminated with circular heads, with such alternate indentations, that they not only fit, but give motion to one another; and should any settlement take place, the joints will not be so much deranged as to materially affect the motion.

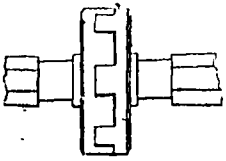


Fig. 1304.

In another variety, calculated to connect a long line of shafts, where there is a heavy strain, Murray's coupling-box is used successfully; and when the shafts are out of line the motion is continued in the same manner as by an universal joint. The two shafts to be united are shown at A and B, and their necks or collars lying on the bearings at C and D. The boxes E and F are fixed on by wedges, and one of them has a projecting piece attached to both sides of it, as shown at *a*. The box F has two similar pieces, shown at *b*, *b*. When the shaft A and box E are turned round, they cut against the screws *c*, of

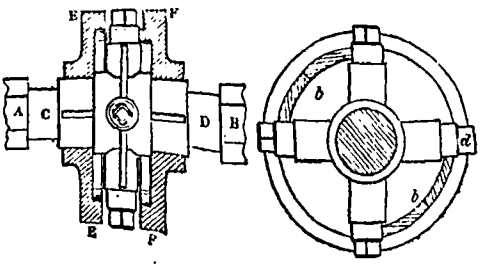


Fig. 1305.

the cross, which is of iron, and contained within the boxes, and cause them to revolve; at the same time the other two screws d, d press against the pieces b, b and put the box F and shaft B into motion.

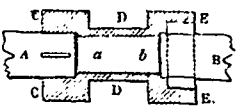


Fig. 1306.

Where there is only one bearing for every length of a shaft this may be used. The two shafts have at each end a pivot fitted into a coupling piece, bored to receive the ends of them, with a neck turned on the outside, which works in a bearing. The two shafts are connected with the coupling piece by means of keys passed through each shaft, and there are notches within the coupling-box which receive the ends of the shafts. The shafts do not fit tight any where but at the pivots, so that there is some freedom of motion allowed, and a slight deviation from a right line does not produce much strain.

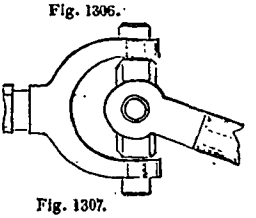


Fig. 1307.

Hooke's universal Joint is a beautiful means of uniting shafts which incline towards each other. By this motion the rotary may be conveyed, when there is considerable inclination from one shaft to another: when this angle is more than 15 degrees of inclination, then bevelled wheels are used to prevent the friction and great irregularity of motion which are the consequences of too great an inclination.

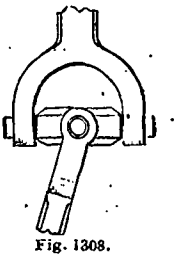


Fig. 1308.

This ingenious contrivance consists of two shafts or axes, terminating in a semicircle, and connected by means of a cross: as the branches have motion round their pivots, it is obvious that when one shaft is turned round, a similar motion will be communicated to the other; such joints are used when the inclination of the shaft does not exceed 40 or rather 140°, its complement. When the inclination is between 50° and 90°, the double universal joint is employed, which has two crosses, with their extremities moving on their pivots in the semicircles at the ends of the rafts. These joints may be constructed with four pins, fastened at right angles upon the circumference of a hoop or a solid ball.

Friction Couplings are employed when the connection is merely the contact of the surface, and is not applicable to heavy machinery; it is employed much in boring instruments. The shaft A has at the end a circular plate, which fits into a loose box at the end of the shaft B. A collar of leather $b b$ within the end of the hollow part of the shaft B, screwed up by the nuts a, a, causes the box D to press against this collar, and the friction produced puts the shaft B in motion.

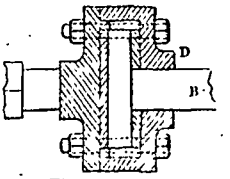


Fig. 1309.

Engagement and Disengagement of Machinery is usually performed by either bands, belts, or chains, the particular object being to communicate motion as steadily as possible, for if given suddenly, fracture of the machinery is too often the consequence. The fast and loose pulley is one of the most simple used, and consists of two pulleys, one fixed on the axle, the other loose, so that the belt which conveys the motion may be placed upon either of them, thus putting the pulley either in or out of motion. The belt inclining to that part of the pulley which has the greatest diameter, it is requisite to have the rim rounded towards the middle, in order to prevent its slipping off.

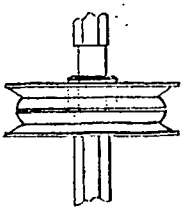


Fig. 1310.

The common Clutch or Gland has a pulley revolving upon a shaft, to which it can be connected when it is required to give motion to the machinery. The axle has a gland or cross-piece attached firmly to it, and upon the wheel, and is so formed as to be able to slide along the shaft when motion is required; by moving the handle the wheel is pressed towards the gland, and the cogs or teeth at the side engage the gland, turning it round and thus put the axle it is connected with into motion. The pulley P, made to revolve upon the shaft A B, is often used for disengaging or re-engaging a machine, moved by a belt or band. D E is a cross-piece or gland attached to the axle, for the purpose of receiving the teeth of the pulley, P, when it is slided along the shaft for the purpose of engaging it, and which is easily performed by the handle E G. It is necessary that the teeth placed at the side of the pulley should be made of sufficient strength, and that they nicely fit the gland they are intended to engage, otherwise the motion in some machines would be rendered irregular.

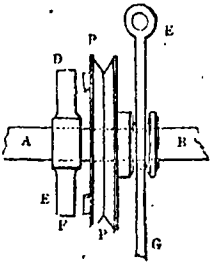


Fig. 1311.

Another method commonly in use is here represented: the shaft to which the machinery is attached can be put out of motion by the means of the revolving wheel C. The end of the shaft A is square; the clutch D is made to slide freely upon it by aid of the handle E F, so that by engaging the revolving wheel C, which is always in motion, the shaft may be made to revolve. The teeth of the clutch should be made of a sufficient strength to prevent fracture.

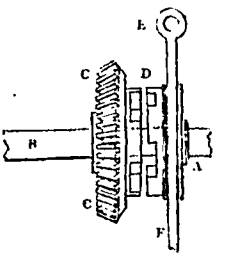


Fig 1312.

The Bayonet Clutch has its arms A A fixed securely to the shaft, or is cast upon it. These arms have holes drilled through them, through which the shanks *f, f* of the bayonet pass. The sliding of the bayonets back upon the shaft puts the whole out of motion, and when they are brought together pass through the holes in the opposite wheel, they carry the shaft around with them. It is perfectly easy by such means to throw the work out of gear, during the time the mill may be in motion; but great care should be adopted in throwing them into gear, as the teeth are subject to be broken, particularly when high velocities are employed. They are consequently only made use of in such machines as rolling mills, and others where there is a slow velocity. The shaft on which the cog-wheel is placed, we may suppose engaged; in turning the machinery we can stop the works by pushing back the shanks *f, f*, which are firmly fixed by nuts to the arm D D, and made to slide upon the shaft; around the central part, *g*, is a circular groove, like that of a pulley, into which a fork may be introduced when it is required to slide the bayonets either forwards or backwards.

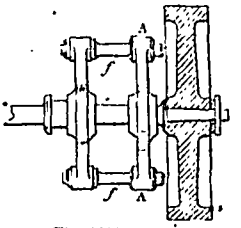


Fig. 1313.

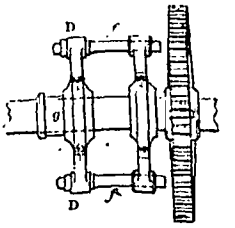


Fig. 1314.

The friction clutch is another modification, and which enables the machinery to be brought into motion more gradually. A B is the part of the shaft put into motion by the mill, and the bayonet is made to slide on the square part of the shaft. The bayonet C D E is made to slide on the square part of the shaft, or to pass through the arms of a cross H I, that is secured firmly to the shaft; F G is the part of the shaft to be connected, and upon it is fastened a drum or pulley, with a hook on the outside, and which is made to press gently upon the drum by screws. When the machine is required to be put in motion, the hoop L M is turned round by the bayonet clutch, and by the friction of the hoop L M upon the drum, a gradual and easy action is obtained. This simple and ingenious contrivance is applicable to large machines, and particularly where any shock or strain given to the works would be injurious.

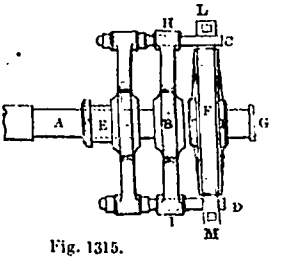


Fig. 1315.

Friction destroys, but does not generate motion, it is therefore unlike gravity, or any other force which, while retarding motion in one direction, accelerates it in another. The force of friction may be said to destroy the law of continuity and motion, and it is of the utmost importance that every means should be adopted to diminish its influence in practical mechanics as much as possible. If power be applied to a machine of any kind, an equilibrium takes place when the velocity of the power is to the velocity of the resistance, as the weight is to the power; in this state the machine may be considered at rest, and incapable of performing any work. If we increase the power, the machine will move with more and more velocity, its motion gradually increasing as long as the power exceeds the resistance; but should the power be lessened, or the resistance increased, the motion of the machine will be diminished until it arrive at a state of uniform motion. This increase of resistance may be produced by an increase of friction, which generally accompanies an increased velocity, or by the resistance of the air, which is always greater as the velocity augments. The power of a machine is therefore diminished by an increase of velocity, and from this cause it is that machines acquire a uniform motion. The force which opposes the production of motion in a machine is the resistance, and the chief of that to be overcome arises from the work to be performed; but there is, in addition, the resistance from friction, and from the inertia of the parts of the machinery, a considerable quantity of the moving power being employed to overcome the first obstacles to motion. An axle with a wheel at each extremity, moved by two currents of water running with different velocities, has at first a slow motion, but if the fall of either be increased, the work will be performed

by that without reference to the other; a diminution of the impelling power accompanies an increase of velocity, and in every machine there is an inertia to be overcome, before we arrive at a motion which will produce the useful effect.

Plumber's Blocks and Steps are the bearings upon which the gudgeons of shafts revolve. The pillows or brasses are made of gun metal, or a composition of copper and tin, which when working with cast-iron acts with little friction. The internal brass or pillow is fitted within an iron frame or casting, one half attached to the lower plate, the other to the upper, and by means of screws and nuts are securely drawn together. In order that the two halves of the brasses may be true, they are turned previously in a lathe, or bored out of the solid, and afterwards separated and put into their respective situations.

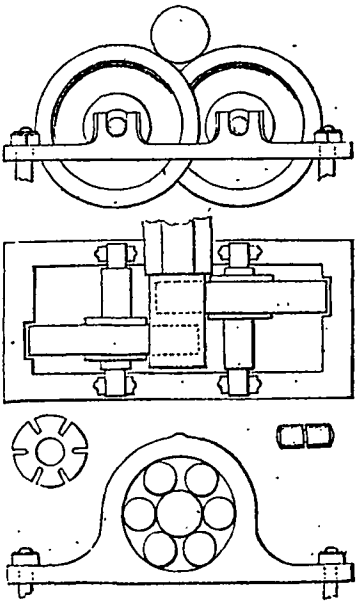


Fig. 1316.

Friction Rollers, or wheels, are used to diminish friction, and their effect is produced by converting a sliding into a rolling motion. Wheels are sometimes employed for this purpose, but the stress is then thrown on their axles, and is not borne on the surface as in the rollers. Friction rollers consist of an iron plate bolted down to the framing, upon which are cast circular rings, whose interior surface is accurately turned; the gudgeon rests in the middle of six rollers, placed at equal distances, and of such a diameter as exactly to fill up the space between the gudgeon and the outer ring. When the revolution of the gudgeon takes place, as the rollers are free to move, they roll round in the same direction, but with a velocity in proportion to the difference of the diameter of the gudgeon and the ring. A groove is formed in these rollers, and an iron ring made to fit upon them, so that they are kept asunder at their proper distances, and truly parallel after the gudgeon is introduced in the middle. The notches in the ring are not made to fit the rollers tightly, but to allow sufficient play, and little friction. The sides of the ring are boxed up, that no dust or dirt can enter to derange the rollers.

Conical Friction Rollers, if not executed very accurately, will wear out of adjustment, and are not of frequent introduction; they are sometimes used to vertical shafts; two conical friction rollers introduced under the end of a shaft, also made conical around the pivot, to play on them, prevents the weight from resting upon the pivot.

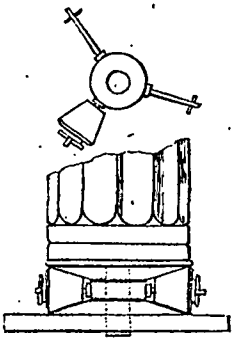


Fig 1317.

Having described some of the first movers employed in the construction of machines, the effect of which is usually rectilinear, it is now necessary to consider them as acting tangentially on the circumference of a circle, producing rotary motion; also to describe the great variety of contrivances to vary these motions, and adapt them to the construction of machines.

Alternate cones are frequently made use of for changing the velocity of motion, when this is required to be gradually and uniformly accelerated: one cone gives motion to the other by a belt, carried along by a guide, by which means the motion is accelerated or retarded. One of the earliest methods adopted for the transmission of rotary motion, with or without a change of speed, is by bands or straps. A series of pulleys or grooves in one common pulley, corresponding with others in another such wheel, so as to preserve always the same length of band, allows a great variety of speed to be obtained by merely shifting the band from one pair of opposite grooves to another.

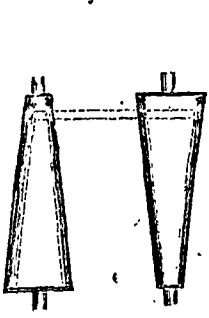


Fig. 1318.

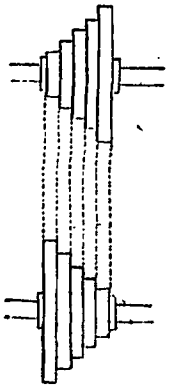


Fig. 1319

Continuous rectilinear motion, with a uniform velocity, or which varies according to given laws, may be changed into a continuous rectilinear motion, with a velocity of the same nature as that of the movement which produces it, constant or variable, according to a given law, in the same plane or different planes.

An endless cord turning round two fixed pulleys gives the idea of rectilinear motion, which is nothing more than the circular and continuous movement of a circle whose radius is infinite. To make a right line pass over the distance ab with a certain velocity, whilst the point c goes over the same distance with the same velocity, a single pulley may be employed, or two pulleys, if the motion is to be communicated in different planes.

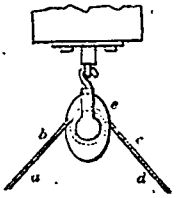


Fig. 1320.

The conversion of rectilinear motion from one direction to another, with either increased or diminished velocity, is usually effected by pulleys and blocks.

If it be required that the point a should pass over three or four times the space of the point c, combinations of pulleys must be employed.

To transform rectilinear movement into circular, as to make the distance ab traverse in a straight line, and with a certain velocity, to the point a, whilst the point e traverses the distance cd with the same rapidity and reciprocally; this is effected generally by means of a reversing pulley, e, or by two, if the two points are to be moved in different planes. If the point c is required to run through two or three times less space than the point a, it is effected by means of the muffle generally employed to move heavy weights.

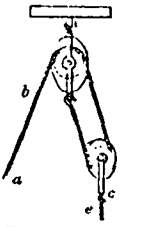


Fig. 1321

Rectilinear motion is changed into continuous rectilinear by the mules of the spinning jennies. The chariot or carriage B, mounted on four wheels, has placed upon it a system of spindles, which are made to revolve by its motion; the power is applied at d, and the carriage is made to maintain its parallelism by means of two cords, mt, sp, the ends of which, n and u, are attached to two fixed points, and pass through two pulleys sm, tp. In like manner the extremities r and u of the second are attached to two other fixed points, and pass through two pulleys placed on the same axis as the first; the points uq and nr being so situated that they are perfectly parallel, and the cords equally stretched. The carriage B, in its primitive position, is made perpendicular to the line uq and nr, and when rightly arranged the perfection of the work is easily maintained.

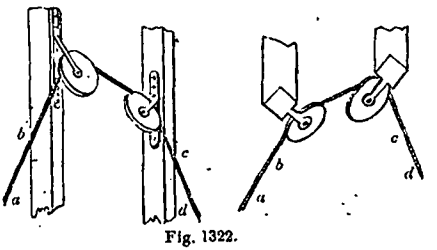


Fig. 1322.

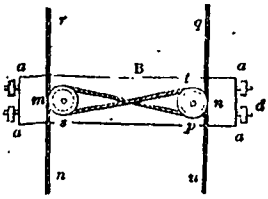


Fig. 1323.

The same problem is performed by the motion of a rule mounted on two channelled or grooved wheels placed near its extremities, and which are equal in diameter, and with their planes truly parallel.

The parallel rule has a variety of forms given to it, but that most generally used by engineers or draughtsmen has two wheels, as c and d, fixed upon a rod, and which, when rolled either backwards or forwards, preserves a parallel distance: it was the invention of Mr. Dollond at the latter end of the last century.

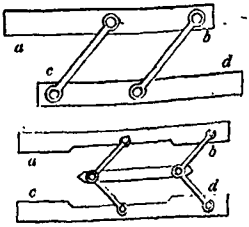


Fig. 1324.

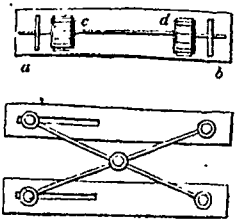


Fig. 1325.

To make one line move in a parallel direction to another there are several methods: the simple rule, made to run upon wheels, or the double, working by means of two bars riveted on them, are the ordinary examples: and Ramsden's movable sights with three rules is another variety.

The rule ab has a horizontal groove running from one end to the other, in which is engaged a small fixed cylinder, but which does not traverse it; d is another rule, made freely to

slide between the two small bridges p and q, and which has a perpendicular rod ef, from one part of which, at a greater or less distance from the rule cd, rises another cylinder, which is inserted, like the first, in the longitudinal groove m of the rule ab; but on the opposite side to that on which is the cylinder c, and in such a manner that when the rules are in motion they do not meet.

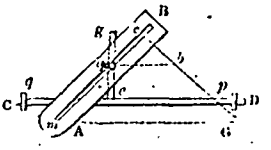


Fig. 1326.

If we move the rule so that its point a goes over the line A G, parallel to the rule C D, the point a will in the same time go over the right line ab. It is thus by the continual rectilineal motion of the point a we can communicate to the rule d a motion of the same kind with the relative velocity we require, and even in a contrary direction by placing the cylinder a conveniently in the rod ef.

Let A be a wedge which may slide in the direction of its length between four pillars, whilst another wedge B is retained by pins, or, what is better for the diminution of friction, by rollers fixed in the same wedge, and which touch the pillars; it is clear if we push the wedge A, B will rise, preserving its parallelism. Supposing the force applied to the wedge A in the direction of the base ab, and a rule lp, perpendicular to the inclined plane ab; the extremity of this rule has a friction roller at l, it leans on the inclined plane, and the rule slides between the bridges c,g.

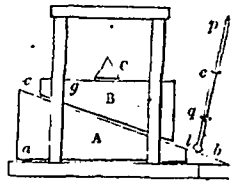


Fig. 1327.

It is evident that, the inclination of the plane being arbitrary, we may transform a continuous rectilinear motion into another, which will form a given angle with the first; the velocity of the first will be to that of the second, as the radius is to the sine cba. If the angle cba were zero, the rule lp would rest motionless, which happens when rectilinear motion is changed to another also rectilineal, but the direction of which is perpendicular to the first; we obtain this result by means of the second wedge B, and if we add a third, C, which forms one body with the second, we may change the direction of motion at pleasure, as well as the ratio of velocities; the line cb may have any curvature, and in this case the continuous rectilinear would be transformed into an alternate rectilinear motion.

Montgolfier's Hydraulic Ram. The current of a river or waterfall is a mover, acting in a constant rectilinear direction, and communicates alternate motion to a valve; this, seconded by a reservoir of air, causes a continuous flowing of water, which may be regarded as a continuous rectilinear motion.

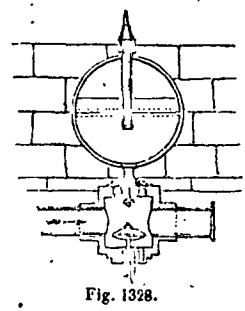


Fig. 1328.

This machine, first constructed in 1797, has been brought to very great perfection since, and in some cases usefully employed. The large pipe, which is called the body of the ram, passes through the side of the reservoir, from which the fall of water is obtained; this pipe generally is formed with a trumpet mouth at one end, and at the other the opening can be closed by valves, through which, when open, the water issues with a velocity dependent upon the height at which it stands in the reservoir from whence the supply is drawn. The valve is made of metal, with a hollow cup or dish attached to its lower surface, and its seat is made a little wider than the diameter of the pipe, which consists of a short cylinder screwed by a flanch into the upper surface of the ram; this cylinder is so formed as to have an inverted cap or annular space round the upper, for containing air, which cannot escape when it is compressed by the water. From this annular space there is a small pipe, communicating with the open air, furnished with valves, one of which opens inwards to admit air, and prevent its return, whilst the other admits a certain quantity of air, and then shuts and prevents any further entrance. When these valves are opened by hydrostatic pressure, a portion of the water flows into the air-vessel, and condenses the air it contains, and the water in it is thrown to a height sufficient to balance the elasticity of the air shut up in the chamber.

Continuous rectilinear motion with a uniform velocity, or which varies according to a given law, may be changed into alternate rectilinear motion, with a velocity of the same nature as that of the movement which produces it, constant or variable according to a given law, in the same or in different planes.

This machine consists of two cylindrical pipes a and b, whose axes are in the same vertical direction; they are separated from each other by an interval dependent on a condition we are about to indicate.

Fig. 1329.

The upper extremity of the pipe a is closed by a plate in which is pierced a circular orifice answering to that in the pipe b. C is a circular diaphragm whose diameter is smaller than that of the orifice dd, a little below which it is placed.

The water from a reservoir enters through the pipe *a*, and tends to rush out through the annular orifice formed by the diaphragm and the edges of the circular orifice *dd*, with the velocity due to the weight of a column of water of a constant and equal height: the dispersion of the annular orifice through which the water endeavours to escape increases the effect of the ordinary contraction of the fluid vein, and forms a cone whose summit entering a certain portion of the tube *b*, determines the distance which should separate the two tubes *a*, *b*.

On the diaphragm a small cone, *f*, of water will be formed; the water rushes into the pipe *b*, and remounts to a height equal to $\frac{2}{3}h$, when the pipe is cylindrical. But if it be conical, it rises to greater and variable heights, by reason of the qualities of the cone; arrived at its maximum of elevation it descends, introduces itself into the stationary cone of water, causes the fluid vein to diverge, and obliges it to rush beyond in a parabolic curve through the interval which separates the two tubes until the tube *b* is entirely full.

The directions of the jet d'eau return to their former position; then the contraction of the vein takes place, and the first effect recommences; this alternate motion takes place in perfectly equal intervals of time; but without the diaphragm the machine would produce no effect.

Continuous rectilinear motion with a uniform velocity, or varying according to a given law, may be changed into a continuous circular motion with a velocity of the same nature with that of the motion which produces it, constant or varying according to a given law, in the same plane or in different planes.

A Cylinder turning on its axis, and a cord which envelopes its surface, gives the solution of this problem and that which is reciprocal to it.

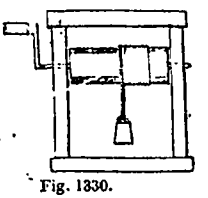


Fig. 1330.

An endless Chain furnished with teeth, which engage a toothed wheel attached to the cylinder, has been substituted for the cord employed in the preceding figure.

Nut and Screw, as applied to the Press.—If on the same cylinder two screws be traced in a contrary direction, they will at the same time communicate two rectilinear motions in opposite directions to the two nuts (female screw).

If the nut be fixed and the screw turn, the screw will have a rotary and rectilinear motion, which is employed for penetrating hard bodies, for uniting them together, for raising heavy weights, &c. M. Zureda contrived a very ingenious machine of this kind, where a cylinder turning round its axis by means of a handle; on the surface of the cylinder two opposite grooves were cut, like the threads of a screw, and which united or ran into each other at both ends of the cylinder. A rod running along the top of a frame, with its other end in the groove, was made, by turning the handle, to follow the spiral direction of the grooves, until it reached the end of the groove, where it communicated with the opposite groove; it then returned through it to its original position.

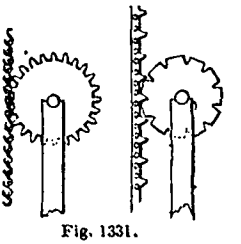


Fig. 1331.

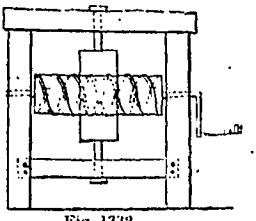


Fig. 1332.

When the screw of the machine in the figure turns without changing its place, the nut must not turn, but have a motion given to it in the direction of the screw, and in this case the circular and rectilinear movements are divided.

The screw is one of the most useful machines in the arts; it is an auxiliary in almost every machine, and readily changes form wherever it may be required; a system of two parallel screws is often used at the edges of a long plank to communicate a rectilinear movement, and preserve its parallelism; and the same principle, applied in an opposite direction, forms the press. When motion is to be generated, the male and female screw are always joined; that is, whenever the screw is to be used as a simple mechanical power; when joined with an axis in peritrochio, there is no occasion for a female, but in that case the screw becomes a portion of a compound engine.

Circular Motion transformed to rectilinear, as illustrated by Prony. *gh* is an axis divided into three parts, *ab*, *cd*, *ef*; the two screws *ab*, *ef*, are of the same gauge, they traverse in two fixed supports *k*, *n*, in which are two female screws; this axis moves horizontally, and passes over at each turn a space equal to one turn of the screw; *ed* is another screw, whose distance be-

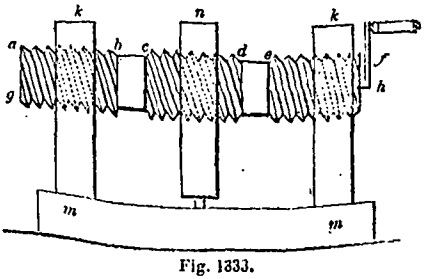


Fig. 1333.

tween the threads is greater or less than the other; into it is introduced a nut n, in which is fixed the thread of the micrometer; this nut cannot turn at the same time with the axis, for it is prevented by the bar mm; but at each turn of the axis it passes over a space equal to the distance between the threads of the screw; it participates consequently in two opposite movements, that of the absolute change of this axis, and that round the axis itself, so that it only advances by the difference of these two motions. Let a be the difference between the threads of the screws, ab, cf; g that of the screw cd; after n revolutions of the axis, the support n will have gone over a space equal $na-n\dot{a}$, equal $n(a-\dot{a})$; but $a-\dot{a}$ may be as small as we please, a and $\dot{a}$ also as large as circumstances require.

A spiral enveloping a cylinder presented to a current of air or water changes the rectilinear motion of these fluids into a circular one, and the screw of Archimedes may be considered as the inverse of the problem. The simplest method of producing a rectilineal alternating motion from a circular continuous one consists in raising a beam or stamper vertically, as that of an oil mill, by wheels formed into an irregular outline, or carrying on their circumference wipers or spirals. The stamper is thus raised to a certain height, and descends through the same height by its own weight, when the succeeding wiper begins to act upon it, and raises it a second time. In the vertical wheel with floats, in the undershot, breast, and overshot bucket wheels, we have at once an example of rectilinear converted into circular continuous motion.

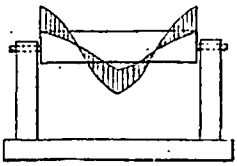


Fig. 1334.

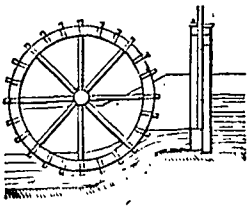


Fig. 1335. UNDERSHOT WHEEL.

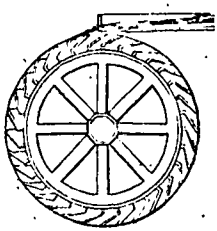


Fig. 1336. OVERSHOT WHEEL.

Horizontal Windmills are composed, first, of a wheel formed by six sail-beams, fixed to the axle c; secondly, of vanes, a,b,d,e,f,g fixed to these sail beams by their pivots, placed in such a manner that their surfaces are divided into two unequal parts by the axis of rotation. If we place in the sail-beams the obstacles r, formed by vertical cords, in such a manner that the distance between each obstacle and the pivots of the vanes belonging to the same sail-beams are smaller than the largest vane, so that they can freely turn, without being able to pass beyond the direction of the sail-beams, which is performed by stops, and other cords placed between those we have mentioned and the points of rotation, it will be seen that in whatever position the vanes are in calm weather, immediately the wind blows, they present themselves to it, so as to turn the axis c always in the same direction—a circumstance which would give a decided advantage to this kind of sail over vertical sails, but for great inconveniences which have thrown discredit on them: of these the chief is the resistance resulting from the action between the wind and the part of the wheel which moves in a contrary direction to it. The continual friction of the vane against the cords also diminishes the effect of these machines, and tends to destroy it: it has been attempted to obviate this by multiplying the number of vanes on the same sail-beam; but the inconveniences from the sails of the horizontal mill are greater than the advantages.

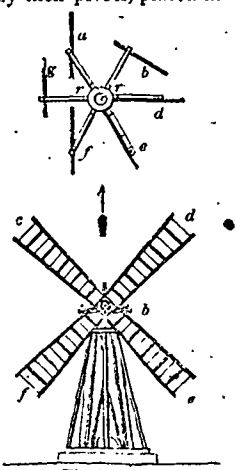


Fig. 1337.

Windmill with a vertical Wheel.—These mills are composed of a turning axle b inclined to the horizon from 8 to 15 degrees: second, of four pieces of wood, c,d,e,f, each 40 feet long, perpendicular to the axle b; they are fixed to the axle at its upper extremity: third, by four sails sustained by these four pieces of wood: each sail commences at 6 feet 6 inches from the turning axle b, and terminates at the extremity of the arms which sustain it; consequently it is 32 feet long, their breadth rather more than 6 feet 6 inches. According to Monge and Hachette, each sail may be regarded as an irregular surface engendered by the motion of a right line perpendicular to the piece which sustains the sail, and which at the commencement of the sail, viz. nearest the turning axle, would form with it an angle of

60° on the windward side of this right line, passing over the whole length of the piece sustaining the sail, and remaining always perpendicular to it, but uniformly increasing the angle which it forms with the turning axle *b*, in such a manner that at the extremity of the sail the angle, which was 60° at the commencement, would become 78° if the axle *b* were inclined 8° with the horizon, or 84° if the inclination were 15, and in proportion for intermediate inclinations. The position of the generating line serves to fix the direction of the cross pieces; together they form a frame which receives the sail-cloth: each sail may also be regarded as an irregular surface produced by the motion of a right line perpendicular to the piece sustaining the sail, and subject to touch in all its positions the right line drawn through the corresponding extremities of the position which the generating line should have at the two extremities of the sail, as previously stated.

The dimensions we have given are those mostly employed in Flanders, principally near the town of Lille. Coulomb estimates the total effect of these mills working the whole year 8 hours per day, as raising a weight of 1000 lbs. 218 feet per minute. Supposing a man employing his strength in the most convenient manner can only elevate, when working 8 hours a day, a weight of 60 lbs. 1 foot per second, which gives 1,728,000 lbs. elevated a foot for the daily effect; we shall have for 8 hours' work per day a weight of 1000 lbs. elevated $3\frac{6}{10}$ of a foot per minute: and as the mill working 8 hours per day raises 1000 lbs. 218 feet in a minute, its effect is equivalent to the daily work of 61 men.

Euler found the angle of 54° 44′ the best for the sail to form with the axis in the intermediate part, and one of 80° at its extremity, and that the velocity of the extremity of the sail should be to that of the wind = 2 + $\frac{1}{11}$. Mills with a horizontal axis, the wheel of which we call a fly, carry four arms each 36 feet in length, perpendicular to the axle of motion, on which is spread a sail more or less inclined to the plane of motion of the wheel; it is generally of a rectangular form, and instead of being a single plane, it is constructed with an irregular surface perpendicular to the corresponding arms. The arm itself is rectilinear, so that the surface of the sail applied to the laths offers a concavity to the action of the wind; the axle should always be parallel to the direction of the wind, and as the wind blows in level countries at an angle of 18° with the horizon, the axle is fixed at that angle.

The arms are thicker near the axle than at the extremities, and the laths which receive the sails are fixed at right angles to these arms: as the axle must always be directed towards the wind, a lever is made use of for that purpose which turns the framework supporting the mill round a fixed vertical axle; sometimes the mill carries a sail on the side opposed to the axle, which occasions the mill to set itself. The reason the wind causes the sails to turn, it must be remarked, is that the action is resolved into two others, one in the direction of the sail, and the other perpendicular to it; from the latter, the pressure is received by the sail, which is decomposed into two new actions, one of which, parallel to the axis, produces no effect, the other, situate on the plane of motion, turns the sail. If two opposite sails were inclined in the same direction with regard to the plane of motion, the pressure they would experience would turn the axle in two contrary directions, in such a manner that the latter would not move; for this reason the inclinations are made equal but contrary to the two opposite sails.

A Mill with a horizontal Axis.—The sails being rectangular, the most advantageous form is that called the *Dutch*, which offers to the wind a surface slightly concave, and whose elements are disposed as follows:—the radius of the sail is divided into $6 + \frac{5}{8}$ parts; the first is set out from the centre at a distance equal to $\frac{3}{4}$ of the unity of the divisions, being designated as No. 1., and that which answers to the extremity of the sail as No. 6.; the breadth of the sails must not exceed $\frac{1}{4}$ of the length, but generally it is $\frac{1}{5}$ or $\frac{1}{6}$. Experience has taught that we ought rather to diminish the angle they make with the plane of motion than increase it; according to Smeaton the sails which enlarge towards their extremities are more advantageous than those which are parallel throughout: the best form is that of a trapezium; at the extremity of the radius, a bar equal to a third of this radius is divided at the point where it intersects, in the ratio of 3 to 2. With sails so constructed we have the best effect, and maintain the velocity of rotation in a constant ratio to that of the wind; this velocity of rotation, measured at the extremity of the sail, should be, according to Smeaton = 2·6 or 2·7 times that of the wind, which agrees with Coulomb's experiments, from which he deduced the ratio 2·5 or 2·6. The sails being established according to the Dutch method, and their velocity being in the ratios of that assigned before 2·6, the work transmitted increases as the surface of the sails, which is a little less rapidly than the cube of the velocity of the wind, and we shall have for the work transmitted in a second according to Coulomb, $P = 2{\cdot}60\,V\,P = 0{\cdot}13\,.\,a\,.\,V^3$ kilogrammes; a formula in which P is the effect in kilogrammes at the extremities of the sails, and in the direction of the motion of rotation of this extremity, V the velocity of the wind in metres, *a* the surface of a single sail in square metres. Regard has not been paid in the experiments to the variation of the density of the air according to the temperature.

Verzy's Steam-engine whose Motion is continuous.—Let *cdef* be a section perpendicular to the axis *o*, of a cylinder whose height is equal to the distance *mn*, which separates it from another cylinder *ghikql*, which penetrates the first in such a manner that they have the same axis, and that the surface of the latter adjusts itself exactly to the upper and lower edges of the first; there will be between the two cylinders a circular channel whose horizontal section will be *mgdhknpqmg*, and the height equal to the plane *pq*, which is attached to the external cylinder, the continuity of which it interrupts: the bases of the inner cylinder are closed by plates of metal, making a small rebate: at the crowns of the outer cylinder they are below the axis *o*, so that the inner cylinder may freely turn round its axis, supposing the outer one fixed: in the curved surface of the inner cylinder two openings are made diametrically opposite to each other, equal in height and in breadth to those of the circular canal; two angular valves are opened which turn on their axis, and tend to close these openings as well as the canal, by means of two spiral springs which are in the upper part of the axis, and whose elastic force may be increased or diminished at pleasure; the axes extend beyond the upper base, and have each a handle whose positions are projected in the directions, *g, m, k, n*; the curved surface of the outer cylinder is pierced by two circular holes, one where the tube *a* abuts, which conducts the steam, and the other communicating with the condenser by means of the tube *b*: suppose then the steam enters at *a*, the plane *pq* opposes its passage, whilst the two sides of the angular valve present the same surface to the steam, consequently it does not change its situation, and its edge will lean on that of the inner cylinder with all the force of the spring *grs*; and this cylinder will turn in the direction of *abc*. Before *me* arrives at the hole *b*, which communicates with the injector, the handle at *k* will meet the obstacle *o*, at which is a small bar fixed to the upper crown of the great cylinder; this forces the angular valve *ikn* to turn inwards; thus going without difficulty past the fixed plane *pq*, in such a manner that when it shall have taken up its first position *mr* will have passed the hole *b*, and the vacuum will be formed, the inner cylinder having made only a half revolution: the action of the steam will continue to communicate a continuous motion of rotation to the axis *o*, which may be applied to any required use.

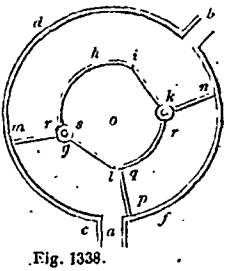


Fig. 1338.

Universal Windmill.—This machine has for its object the immediate transformation of the rectilinear motion of the wind to circular, and is more curious than useful. Let *aceg* be the equator of a sphere whose radius is *kl*, and *kpep* the vertical projection of the meridian, which cuts the equator in the diameter *ke*. In the upper part of the plane of the equator draw the two diameters *ae, cg*, perpendicular to each other; and in the lower part of the same plane the two other diameters *dh, bf*, which form angles of 45° with the preceding; in the upper part of the plane of the equator are constructed four curves formed by the surfaces of cones whose summits are at *e, g, a*, and *c*, and whose bases are oppositely curved; which results from the intersection of the surface of the sphere with the right cylinders, which cut the equator in the curves *l, e, f*, &c., tangential to the lines *lg, hl, al, bl*, &c., and through the corresponding parts of the surfaces of the two meridians *eg, ae*, and of the equator. In the lower part of the plane of the equator are also placed four curves constructed according to the same principles; the summits of the cones are at *dl, hb*: the curves *l, g, h* are traced by geometrical principles, viz. from the summit *g* of the triangle *lgh*, the line E M is drawn to the middle of its base; at M is elevated a perpendicular M*e* equal M*e*: the circle *le'f* drawn tangential at *f* and *l* to the two sides *gl, hl* of the isosceles triangle *lgh*: from each point N of the line *lf*, two lines were drawn, one parallel to M E', which is terminated at *n'* in the arc of the circle; and the other N*n* equal to the first, and parallel to M E, which gives a point *n* belonging to the line L*e* F, required to be drawn.

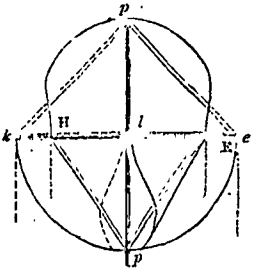


Fig. 1339.

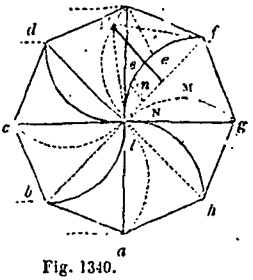


Fig. 1340.

It must be observed that, in consequence of the very small angle at which the sail of the vertical windmill is inclined to the direction of its motion, which generally is not more than 20°, and of which angle the sine, which represents the force to give motion to the sails, scarcely exceeds one-third of the radius, much of the power of the wind is lost: on this account horizontal sails were introduced, under the notion that more power could be acquired; numerous contrivances for this purpose are contained in the Repertory of Arts.

Danaide, Marquis Mannoury d'Ectot: this machine may be classed among hydraulic wheels; it consists of a cylindrical cistern of wood, *d d*, whose bottom is pierced in its centre by a circular orifice *r*, through which passes a vertical iron axle *p*, retained above by a collar, and resting at its lower part on a pivot which allows it to turn on itself, drawing with it the cistern to which it is firmly attached by means of four iron crosses, two of which, *c, c*, are shown in the section, and the two others *d d, e e*, in the section *b*; this axle directed in the axis of the cistern does not completely close the central orifice which it traverses. On the other hand it leaves around its circumference a circle through which the water can escape by a circular diaphragm *s* fixed to the vertical axis *p*, and to the crosses immediately below the latter: divide the cistern into two equal parts, which cannot communicate with each other, except by the circle which remains between the circular diaphragm and the inner surface of the cistern: the lower part *c d, d c* is divided into eight cases by as many diaphragms, four of which go from the axle *p* to the circumference, and the four others do not touch the axle, so as not to obstruct the orifice *r*; these diaphragms formed by plane surfaces descend from the circular diaphragm to the base of the cistern; the water enters at the upper part of the cistern by the conduit pipe *b*, which is bent conveniently to allow it to issue through an orifice *x* in the form of steam, which strikes tangentially the concave surface of this part through its whole height, puts the cistern in motion, descends to the lower part by the circle constructed between the diaphragm *s* and the inner surface of the cistern, engages in the partitions before indicated, and then issues through the orifice *r* to fall into the discharge pipe *r*. Such is the description and play of this machine, executed with the greatest success in different manufactories; an improvement was made in it, by substituting for the diaphragm *t* with plane surfaces, others in a spiral form, prolonged to the upper edge *n* of the cistern through the hollow crown in the centre; the form given to these new diaphragms allows the edge *n* to be suppressed, which prevents the water from spreading beyond; by this modification the loss of active force is considerably diminished.

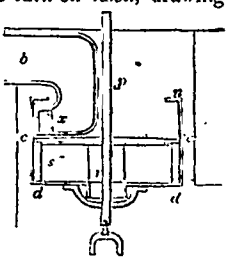


Fig. 1341.

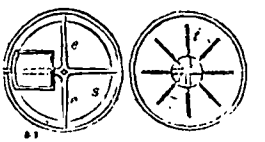


Fig. 1342.

Machine of Cagniard Latour is composed of two cisterns, *a* and *b*, the first filled with water at the ordinary temperature, and the second with water at 75° centigrade; in the first cistern is plunged an Archimedean screw C, in the second a bucket wheel *d*; a tube communicates the bottom of the first cistern with that of the second; if we turn the screw in a direction contrary to that necessary for elevating the water contained in the cistern, it will cause the atmospheric air to descend, and following the direction of the tube of communication, will escape at the orifice *e*, the distance of which from the cistern *b* should be less than that of the orifice *r* from the surface of the cistern *c*; the cold air thus carried to the bottom of the cistern filled with hot water dilates, enters the buckets whose opening is turned downwards, and drives the wheel *d*. In the machine executed by Cagniard, the effect produced consists of raising, by means of a cord attached to the axle of the wheel, a weight of 15 lbs. with a uniform vertical velocity of 1 inch per second, while the moving force applied to the screw is only 3 lbs. with the same velocity: the effect of heat is to quintuple the natural effect of the moving power; the effect of the moving power being quintupled, we may take from it a force with which to supply the moving power, and there will then remain a disposable force of four times the moving power. The Archimedean screw thus employed forms an excellent blowing engine.

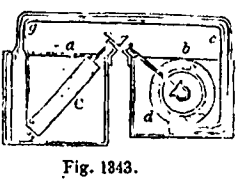


Fig. 1343.

A Gin, where a muffle is not employed, we obtain the ratio of velocities required but by substituting for the ordinary cylinder another whose axle is composed of two parts, *a* and *e*, of different diameters; a cord, after being turned on the part *a* of the axle, passes through the movable pulley which supports the weight *p*, reascends and passes through another pulley, and is then attached to the other part *e* of the cylinder, round which it is enveloped in a direction contrary to that in which it is wound round the part *a*; by turning the cylinder the cord winds on the part *a* while it unwinds from the part *e*, the power being applied at the extremity of the lever *c*. It may be easily conceived that at each turn of the cylinder, the weight *d* only goes over a space equal to half the differences of the two circumferences of the cylinders *a* and *e*, a quantity which we may render as small as we please.

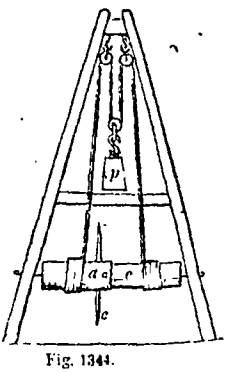


Fig. 1344.

Continuous rectilinear motion with a uniform velocity, or varying according to a given law, may be changed into circular alternate motion with a velocity of the same nature as that of the motion which produces it, in the same plane or in different planes. Fig. 1345. represents a method invented by Perrault of applying a fall of water to the movement of a clock: the water which flows through *c* falls into a small chest *e*, which turns round an axis *a*, and is divided by a partition into two parts: when the base is horizontal the water flows in such a manner as to be divided into two equal parts; by the partition in any other position the fall is into the elevated part; in that represented by the figure the fall takes place in the side *e*; when this part is full, the chest turns on its axis and leans on the obstacle *r*, emptying the water whose weight has decided its motion; the other part is filled in its turn, and restores the chest to its primitive position.

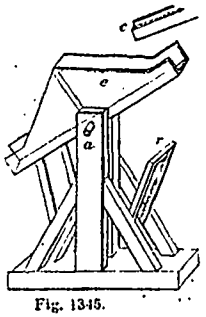


Fig. 1345.

Continuous rectilinear motion is converted into circular motion by means of a descending weight attached to a cord wound on an axle, as we have already described: but to convert a reciprocating rectilinear motion into a continuous circular for a long time baffled the skill of our mechanics; it is, however, now generally effected by means of a *crank* applied in three different manners: *first*, where the moving force may be uniform, and in a straight line; *second*, where the moving force may be uniform, and in a curved line; and, *thirdly*, where in either case the force may be variable. A crank increases also the velocity of the moving force in the usual construction, in the ratio of the circumference of a circle to twice its diameter; but this ratio, as well as the action of the power, varies: for the crank motion which converted the reciprocating motion of a piston rod into a rotary one, a patent was granted in 1769, 1778, and 1781; that invented by Steed was the most simple. Mr. Watt in 1781 obtained a patent for five other kinds of crank, one of which was the sun-and-planet-wheel motion, which he applied to his expansive steam-engines: the "Annals of Science" show how great was the difficulty of converting a reciprocating rectilinear motion into a circular one, and by what patient investigation and labour it was overcome.

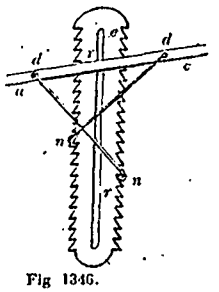


Fig 1346.

To transform circular alternate into continuous rectilinear. — Let *a c* be a lever turning on its axis *e*; *r r* a bar which may ascend and descend freely, and whose edges are ratchet-toothed; *d n*, *d n* are two small levers turning on their axes *d*, *d*, and whose extremities *n* and *n* are furnished with small cylinders, which engage the teeth of the bar; the circular alternate motion of the lever *c* will cause the bar to mount.

A boat at anchor in the middle of a river attached to a cable sufficiently long will go from one bank to the other with a circular alternate motion by means of its rudder, a method often employed in crossing a ferry.

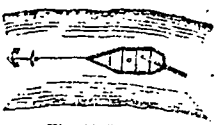


Fig. 1347.

A sector surmounted by a sail whose centre of gravity is very much below that of oscillation, by means of a counterpoise, continually balances itself with a circular alternate motion, when the wind strikes the sail. This method of applying the action of the wind has often been proposed, and models on this principle are found at Paris.

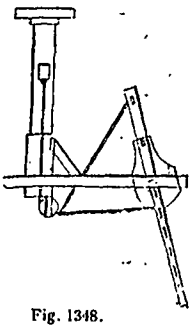


Fig. 1348.

Continuous rectilinear motion with a uniform velocity, or which varies according to a given law, may be changed into continuous in a given curve, with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law, in the same plane or in different planes.

Rectilinear continuous motion with a uniform velocity, or which varies according to a given law, may be changed into alternate in a given curve with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law, in the same plane or in different planes.

Continuous rectilinear motion may be changed into continuous circular by the means before indicated.

Circular continuous motion, with a uniform velocity, or which varies according to a given law, may be changed into alternate rectilinear, with the velocity of the same nature with that of the motion which produces it; constant or variable, according to a given law, in the same plane or in different planes.

Let A B D E be a wheel, which turns round its centre C in the same direction A B D E with a uniform velocity, *m n* a rule which is obliged to preserve always the same direction, whilst its extremity, *m*, follows the centre of a curve drawn on its surface, the other *n* should make a determinate number of alternate motions of a given extent, returning at each revolution of the wheel to the same point of departure with a velocity altogether uniform, which varies according to a certain law, or is arbitrary.

If the ratio of the velocities is uniform and follows given laws, the curve which it would trace would be uniform, and easy to construct.

If the ratio of the velocity is arbitrary, there is an infinity of curves, which may satisfy the conditions of the problem either by rectilinear polygons or curves: rectilinear polygons give two acute angles; therefore curves are preferred, taking care to choose those which form the most obtuse angles; for this purpose it is necessary to diminish the velocity by changing the direction, and that the curve should have the greatest possible extent, by giving the circle the greatest radius that circumstances may allow.

If it be required that during the revolution of the wheel ABDE, the extremity, *n*, of the rod, *m n*, make three alternate movements, whilst the point A describes the arc from 0 to 5, from 5 to 9, from 9 to 10, from 10 to 13, from 13 to 19, and from 19 to 24.

If it be required that the motion should be uniform, divide the centre space, which the point *n* should go over, and which for greater clearness is drawn above the figure, in such a manner, if it be possible, that the equal divisions fall at the extremities of the rectilinear oscillations: in the figure it is divided into 24 equal parts. The circle ABDE is divided into the same number of equal parts, and radii are drawn to the points of division: from the point 5, the furthest from the space that the point *n* should go over, we have taken a distance which enters a little into the circumference of the wheel, and this distance gives the length of the rod *m n*: the extremity *n* is supposed at *o*, the other extremity, *m*, is at *a*, which will be one of the points of the curve; we have taken with the compasses the distance *o* 1, which we have set off from *a* to *r*, and the distance *r* C = C *q* has given the point *q* of the curve,

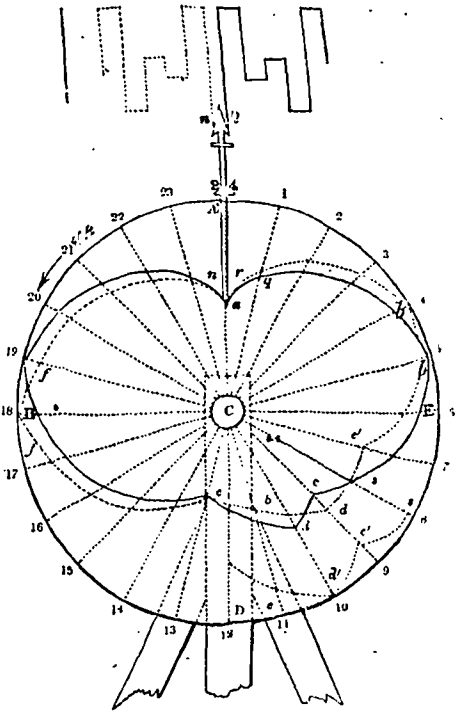


Fig. 1349.

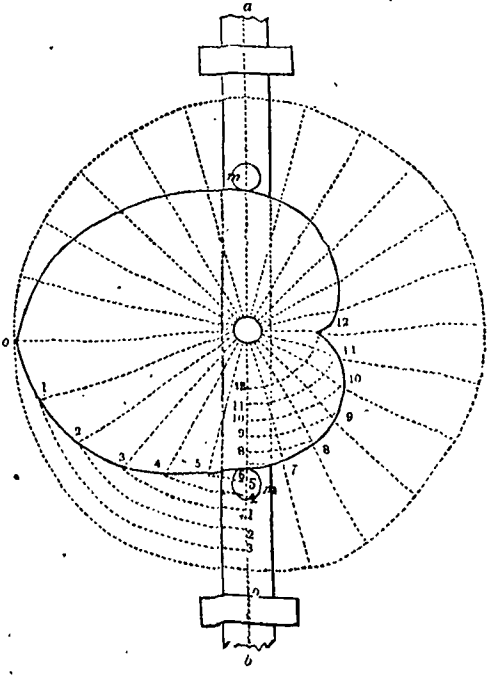
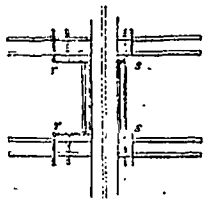


Fig. 1350.

so that when the division 1 of the circle is found at A, the extremity *n* of the rod will be at 1 figure *a* of its course: in this manner we have drawn the whole curve *a q b c d e f a*; at one corner of the figure we have drawn a portion, *s c d t*, of the curve, which corresponds to the part *s e d* of the curve of uniform motion, to show that angles become more obtuse when greater extent is given to the figure; if the problem were subject to no law of velocities, it is evident that the rectilinear polygon *a b c d e f* would satisfy these conditions, but in the application to the arts acute angles not being the most convenient, curvilinear polygons are preferred, represented by the dark lines; the march of the extremity *n* of the rod is indicated by the numbers which mark its place in the line 0, 1, 2, 3, 4, 5, 6, &c.

Fig. 1350. is a peculiar example in which we obtain at each revolution of the wheel a single alternation with a uniform velocity, the curve being symmetrical, and all its diameters equal: advantage is taken of this circumstance to fix the rule, *a b*, to the curve by means of two bolts, *m*, *m*, furnished with pulleys to prevent friction; the alternations for the directing the silk in the bobbins for the spinning machines are moved by this same curve; it is used in various hydraulic machines to give a uniform motion to the pistons of pumps.

Let *b b b* be a plate of metal, in which are cut the slits *a*, *a*, *a*, &c.: behind and near this plate imagine another in which is placed the spiral slit, marked by the double dotted line, and drawn according to the same principles as the heart-shaped curve (fig. 1350.): hence it is evident if the small cylinders traverse the intersection of the slits with the spiral, and that they cause the plate behind to turn, all these cylinders would retire from, or approach the centre of the plates by the same distance; suppose elbows added to these small cylinders in the direction of the radii, whose length should be such that their extremities terminate in the circumference of a circle, whose centre should be the same as that of the plate, it is evident that the extremities of the elbows, whether they approach or whether they retire from the centre will always be found in the circumference of a circle concentric to the first: two similar mechanisms may be placed above each other, as is seen in the figure, and the extremity of the elbows may be joined by bars, which will form a sort of cylinder, whose diameter may be increased or diminished at pleasure by the instantaneous motion of rotation communicated to the plates cut in a spiral shape. Such is the ingenious mechanism adopted for lathes and other machines, in which it is required to change the ratio of the power to the resistance according to necessity, and that almost instantaneously.



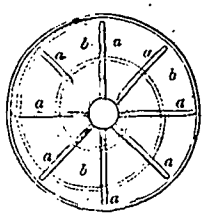


Fig. 1351.

The wheel *a* has its circumference cut in the shape of teeth, which may vary in form at pleasure. The rod *a* leans constantly against the teeth of the wheel *a*, by means of a spring or weight, and slides between the tenons *c*, *d*, preserving its position perpendicular to the plane of the wheel; when the wheel turns, it will communicate to the rod an alternate rectilinear motion, and we can vary this motion as we require. The tracing of the teeth of the wheel offers no difficulty.

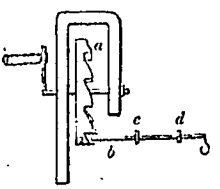


Fig. 1352.

M. Zureda, an eminent engineer in Spain, has applied this to a machine for pricking holes in leather and making cards; it has also been employed in the manufacture of fishing nets, as shown in Leupold's Theatrum Machinarum, vol. ii. fig. 3. plate 36. If all the teeth in the wheel *a* were reduced to one, the surface of the wheel would be an inclined plane, and the oscillations of the rod *b* would be performed in every revolution of the wheel.

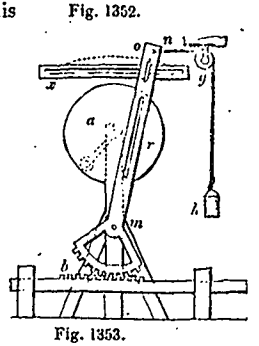
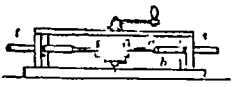


Fig. 1353.

The circle *a* turning round its axis, with a point or pin fixed on its surface, traverses the groove *n* of the lever *n*, whose centre of rotation is at *m*: it results from this that its circular uniform motion is changed from *continuous* to *circular alternate*, which the extremities of the lever, *n*, pass over, but not with uniform velocities If we fix at the lower extremity a toothed arc of a circle, which engages a rack *b*, we have a rectilinear alternate, but not uniform motion. By means of the pulley *g*, and the cord fixed at *o*, sustaining the weight *h*, we obtain a rectilinear, but not uniform motion. The intersection of the groove drawn on the lever *n*, with the other groove drawn on the fixed rule *x*, where a small cylinder may be

placed, serves to communicate to the latter body a rectilinear alternate, but not uniform motion.

a is a wheel partly toothed, which turns in the same direction on a fixed axis; *b c* is a frame, two of whose opposite sides are cut into a rack; to the extremities of this frame the bars *b s*, *c t* are fixed, which form a single body, and which pass through the tenons at the end in such a manner that the rack and the two bars which may be regarded as one, *s t*, may require an alternate rectilinear motion from the circular motion of the wheel *a*. We may also apply the frame which contains the two racks to a bar, by a simple change of construction: this motion is applied to the alternate motions of pistons of pumps, sawing machines, &c. By suppressing one of the two racks, and furnishing the whole wheel with teeth, we transform alternate circular to alternate rectilinear motion.



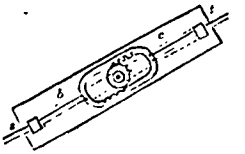


Fig 1354.

The frames of the preceding machine is enlarged by prolonging the two racks in such a manner that they abut on the two small sides, where they unite in the form of a half circle, and the whole wheel is furnished with teeth. It is necessary in this case to employ two cross pieces to communicate at the end of each oscillation a slight lateral movement to the frame, to facilitate the change of gear: in general this motion presents difficulties in execution, and it does not appear capable of producing great effects.

Fig. 1355.

This motion is applied to transform the circular continuous motion of a horizontal axis to vertical alternate rectilinear, which work the piston of a pump, producing a slight balancing in the frame.

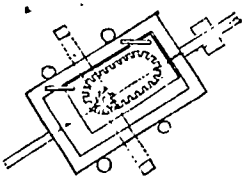


Fig. 1356

Fig. 1357. is a modification of the same motion; having reduced the teeth of the rack to one, the number of that of the wheel is also diminished, and in their place arms terminated by small wheels are substituted, to diminish friction. It will be easily seen that the rectilinear form of the tooth of the rack occasions an inequality of the velocity in the alternate motion; this may be varied at pleasure, or the law of velocity rendered uniform, by giving a convenient form to the teeth. This construction is preferable to that of fig. 1354. for machines exposed to very great efforts, which small teeth could not resist.

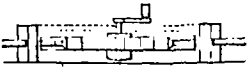


Fig. 1357.

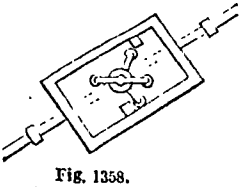


Fig. 1358.

In fig. 1359. *a* is a wheel turning on its axis, *n*, *m* two cheeks to keep steady the sliding bar *p q r s*, which is in the shape of a T; a pivot traverses the groove, and the circular motion of *a* communicates an alternate motion to the bar. This alternate rectilinear motion, very slow at the end, and accelerated towards the middle of the oscillation, is very simple and of easy execution; it is a modification of fig. 1354., and is employed for churns. The circular continuous motion of the wheel can be transformed to rectilinear alternate.

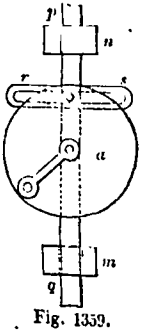


Fig. 1359.

The contrivances that have been devised for converting a circular continuous motion into a rectilinear alternate motion are very numerous, and many highly ingenious; the simplest methods of producing a rectilinear alternating motion from a circular continuous one are those shown in figs. 1361, 1362, &c., where a beam or stamper is raised vertically by wheels formed into an irregular outline, or carrying on their circumference wipers or spirals; the stamper is thus raised to a certain height, and descends through the same height by its own weight, when the succeeding wiper begins to act upon it, and raise it a second time. The same is produced by the rack and pinion, provided the pinion has teeth only on a part of its circumference: the toothed wheel elevates the rack, which descends when the last tooth has ceased to act, and by the time the last tooth has ceased to act, and by the time the rack has performed its work, the toothed part of the pinion has come round again, for the purpose of raising the rack a second time.

It is easy to render the alternate rectilinear motion of the rule $pqrs$ of fig. 1359. uniform, by substituting for the rectilinear groove another drawn in a convenient manner, as here shown. Divide the distance Cs into a certain number of equal parts, for example into six, and divide the quarter of the circle s D into the same number of parts: it is evident the conditions of the problem will be answered if the point of the rule which answers to that where the pivot s is, found also in the division of the radius s C, at the same time that the pivot coincides with the divisions of the arc s D. We must then determine the positions of the divisions of the curve in such a manner that each of these points should be placed relatively to the point s, as the points of the arc s D are placed with regard to the points of the radius s C, which does not offer the least difficulty. We do the same with regard to the three other portions of the circumference, but it must be remarked that there are three different cases to consider; that whilst the pivot s goes over the second portion of its course, the rule pq advances towards its extremity q an equal space, larger or smaller than that it goes over, whilst the same pivot goes over its first space s D. In the first of these three cases we have the form of the figure 8 placed horizontally, that is to say, the points m and n touch; in the second its form is that indicated by the figure; in the third the branches intersect in two points.

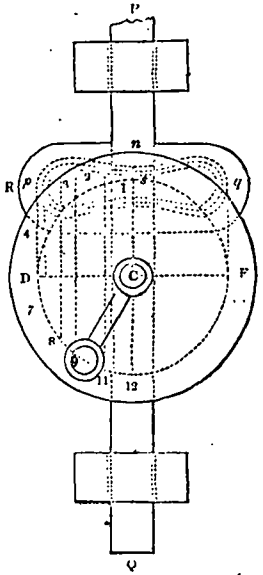


Fig. 1360.

The second of these three cases is that to be preferred in practice: we envelope this curve by another to form a groove capable of containing the pivot s, furnished with its friction roller; the rectilinear groove of the preceding figure may be cut through, but that of which we are speaking ought not to be, in order to tie the interior nut or surface, enveloped by the one curve, with that terminated by the other.

Fig. 1361. a is a vertical rule sliding between two rings n, m; at its lower extremity is attached a pestle; one of the sides of the rule is furnished with a rack in which the toothed portion of the wheel c engages the other part, which is not furnished with teeth. Suppose the pestle c falls by its own weight on the body o; if the wheel c turns from left to right, its teeth will oblige the pestle to rise, but it will fall again immediately afterwards by the deficiency of the teeth in a part of the wheel, and this alternate motion will last as long as the wheel shall continue to move. It is also a particular motion of fig. 1354.

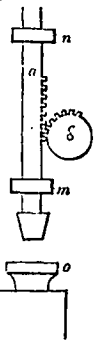


Fig. 1361.

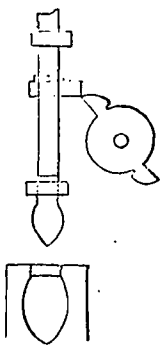


Fig. 1362.

Fig. 1362. is a modification of the preceding; we reduce the teeth of the rack to one, and furnish the wheel with wipers, whose curvature is such that the resistance becomes constant.

The circular motion of the wheel a communicates by the intervention of the rule m a rectilinear alternate motion to the rule n, which slides between two tenons; the reciprocal motion will take place if a performs the functions of a fly. The extent of the alternate rectilinear course of the rod n increases or diminishes in proportion as the point of rotation m approaches or retires from the centre of the circle a. If we suppress the rule n, and cause the rule m to pass across the circular opening, which we may suppose to be made in the tenon, the rule m will have a compound alternate motion.

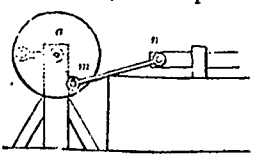


Fig. 1363.

Fig. 1364. A B is a cylinder turning on its axis, and on its surface are two grooves, like that of a screw, cut in opposite directions, and which tend to unite at the two extremities of the cylinder; C is a salient piece which exactly fits the groove, and which surmounts a rod C D, traversing a groove cut in the cross piece E F; the circular motion of the cylinder causes the body C to go backwards and forwards by its alternate passage from one of the helices to the other; this motion is very ingenious, and may be variously applied.

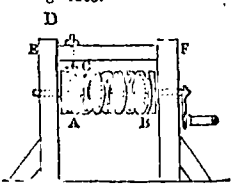


Fig. 1364.

Fig. 1365. *a b* is a cross-piece pierced with a groove, in which the axis of the toothed wheel *e* may move freely; *c* is a bar furnished with teeth which engage a wheel, and which is fixed to the rule to which the alternate motion in a right line is to be given, sliding between the two tenons *d, d*. When the toothed wheel *e* has arrived at the end of its course, the obstacles *n, n* meet the springs to force it to return and engage afresh.

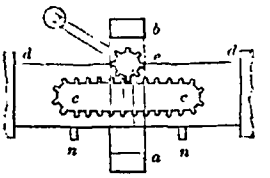


Fig. 1365.

Fig. 1366. *a* is a crown wheel, whose interior is toothed; *b*, a circle also toothed, whose diameter is equal to the radius of the crown with which it engages. The crooked axis turns in the centre of the crown, sustains on one side the centre of the wheel *b*, and on the other a handle to the power which communicates the motion of rotation to the wheel *b*. Whilst this wheel turns round its centre, passing over the contour of the crown, each of the points of its circumference traces a diameter of the crown.

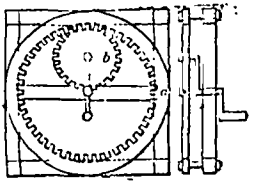


Fig. 1366.

The two toothed wheels *a* and *b* produce an alternate motion, the number of whose alternations, their extent and velocity, may vary to infinity, either by the different ratios of

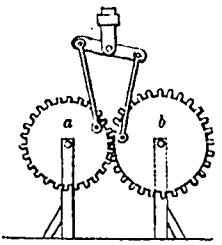


Fig. 1367.

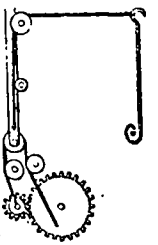


Fig. 1368.

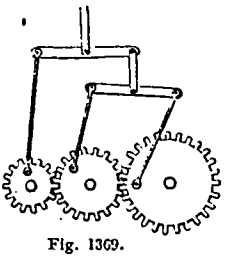


Fig. 1369.

their diameters, or by the different arrangement and proportions of their parts, but all these movements may be exactly imitated by fig. 1349. Figs. 1368. and 1369. exhibit the same motions.

Fig. 1370. is a circular crown furnished with teeth on both its concave and convex sides: it is fixed to a large circular disc *d*, which turns on its axis, leaving a part void, so that the toothed wheel *d* can pass freely; it is terminated by two portions of arcs of circles also furnished with teeth. The toothed wheel *d* turns round its axis, which has the facility of moving in the groove *m n*. The two springs leaning alternately on the two stops determine the alternate circular motion of the disc *d*. The alternate circular motion of the disc *d* serves as an intermediary, communicating to the body another alternate rectilinear motion by means of an endless cord, which envelopes the disc and passes through the two pulleys *s, t*.

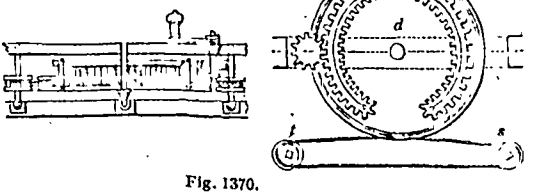


Fig. 1370.

In this figure are united two well-known methods of transforming circular continuous motion into alternate rectilinear, either by employing a bent axle, or a circle whose plane is inclined to its axis of rotation. The hydraulic wheel causes the vertical axis to turn: this axis carries a circle whose plane is inclined to it; the vertical rods of the piston have catches or stops furnished with friction rollers, and lean on the edge of the surface of the inclined circle; thus the circular motion of the vertical axis of the hydraulic wheel communicates an alternate rectilinear motion to the piston rods; the rods of the piston are maintained in the vertical position by grooves furnished also by friction rollers; a double catch, viz. one which applies itself against the lower surface of the circle serves to aid the piston in its descent, and renders the motion more uniform.

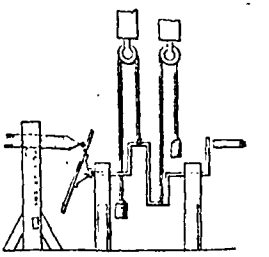


Fig. 1371.

The great wheel r (fig. 1372.) turns round its axis; its surface is furnished with three rollers, on which the roller q successively leans, at the end p of a lever pgh, whose arms make a right angle; the other end tends to turn by the action of a spring or weight the lever p towards h; the extremity h will have an alternate circular motion, which will be changed to alternate rectilinear by means of the pulley f.

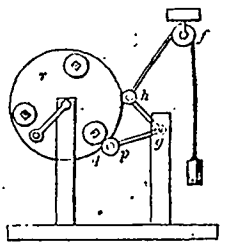


Fig. 1372.

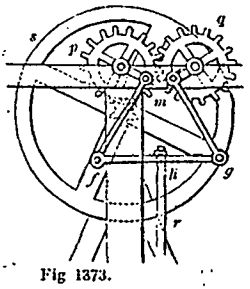


Fig 1373.

s (fig. 1373.) is a fly-wheel furnished with a pinion; p and r are teethed wheels engaging each other; p also engages the pinion: two winches are fixed to the axis of the wheels p, q: mf, mg, are two rods whose ends turn freely and communicate to the rod pr an alternate rectilinear motion, while the fly s turns circularly in the same direction; reciprocal motion is also obtained by this arrangement; it is applied to engines or pumps.

a is a toothed-wheel put in motion by the pinion b, which obeys the immediate action of the mover; the weight is suspended to the extremity of the cord d, which passes through a pulley, and is rolled on the axle c of the wheel a; t is the gudgeon of the same wheel. The brake consists of a lever turning on the axle of rotation; it is furnished with a concave piece p, which should apply itself to the axle c, and a counterpoise h, which serves to raise it as shown in the figure; the obstacle r maintains the break in this position: when it is required to discharge the weight suspended by the cord d, the pinion b is drawn from the toothed-wheel a; the weight falls, and when it is 3 or 4 feet from the pavement, where it would be broken, the extremity m of the lever is heavily pressed, and the piece p by its friction on the axle c immediately stops its velocity.

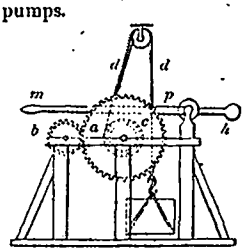


Fig. 1374.

Let a be a drum fixed to the axle of the machine, furnished with a ratchet-wheel turning in the direction indicated by the arrow; m is the lever of the brake, c a catch suspended by a cord at the extremity of the lever b which turns from the point, and leans on the small pulley at the extremity of the brake m: the piece e prevents the catch from mounting by means of a salient point, while the spring tends to approach the ratchet-wheel, and by its curvature sustains it when it is in motion; when the motion becomes retrograde the catch is drawn back, the brake acts, and the machine is stopped without shaking, and consequently with the least possible inconvenience.

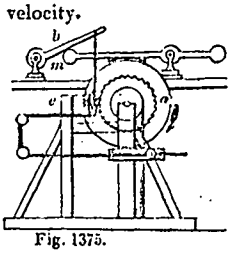


Fig. 1375.

Wheels used at the Stone Quarries, Paris. — A large beam q turns round a fixed point, and sustains on one side the wheel a, and on the other a counterpoise p capable of lifting the wheel a; the whole forms a system similar to the Roman steelyard, loaded with a weight whose place is here supplied by the wheel a; and the running weight is replaced by the counterpoise p, capable of lifting the wheel a: bc is an upright, fe a beam which turns round a point f, and which carries the brake q; ed a rod of wood or metal turning round the axes of rotation e and d; nn the cord which serves to draw up the stones from the quarry; pr a ratchet-wheel fixed to the axle-wheel a, with its catch v fixed to the upright bc; on the other side of the wheel a should be another upright gh, to sustain the other axle of rotation of the lever q, which should have the form of a fork in which the wheel a enters, and whose sides should leave the space necessary for giving it a free passage. The stone to be drawn up is attached to one

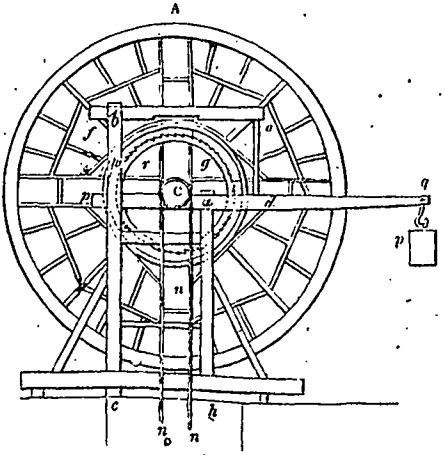


Fig. 1376.

of the extremities of the cord *r*, and the first efforts made to put the wheel *a* in motion in the direction indicated by the arrow causes it to descend until the extremity leans against a stop; the brake *q* then rises, and the workman experiences no difficulty; he can suspend it at pleasure by the ratchet-wheel, and if the cord breaks at the moment the wheel rises by the action of the counterpoise *p*, the brake *q* descends, and the force of the fall is broken.

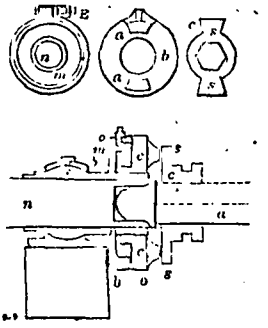


Fig 1377.

Fig. 1377. Let *a* be an axle put in motion by the power *n*, that which communicates with all the other parts of the machine: it is required, that in the case where the resistance experienced by the machine is greater than the limit assigned to it, it should stop without the mover suspending its motion, and without the communication being interrupted between the two axles *m* and *n*: *bb* is the piece of iron fixed to the axle *n*; it is composed of a circular plate whose surface on the side of *n* is plane; that turned towards the axle *m* is furnished with two circular crowns *nn* and *mn*: *cc* is another piece of iron formed of a circular plate; its surface on the side of the piece *b* is furnished with a circular crown which fits in the cavity of the piece *b*, and of a tooth *d* in the opposite surface; there are two salient pieces *a*, *a*, destined to meet the salient pieces *s*, *s*, of the piece *c*, and a strong salient beak *b*, which is prolonged towards the opposite surface, and enters the hollow which the exterior of the ring or circular spring leaves; this embraces the throat formed by the edges of the piece *b*, and its crown *mm*; this ring or brake may be closed more or less by means of a key E, and consequently the friction is increased or diminished at pleasure, in order that the axle *n* may stop, and the axle *m* continue its motion; the latter will conduct the piece *b*, and the brake where the communication shall be established, by means of the piece *c* which turns with it, and can slide in the direction of its axle: the two salient teeth *s*, *s*, meet the obstacles *a*, *a*, of the piece *b* when we bring *c* to *b*; by drawing them asunder, the action of the mover is suspended, whatever be the resistance the axle *n* experiences: it is evident if we screw tightly the key E, and establish the communication by bringing *c* to *b*, the two axles *m* and *n* will turn as if they were one: if we release it entirely, the axle *m* will draw in its motion the piece *b*, and the brake *oo*, but the axle *n* will remain at rest; we then screw the key until *n* turns again. Belancourt has applied this to a machine for cleaning ports, at St. Petersburgh.

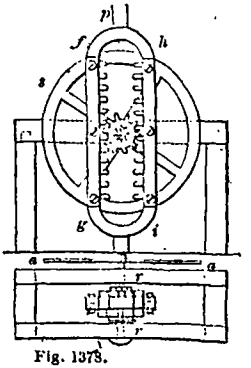


Fig. 1378.

Fig. 1378. *s* is a fly, one of whose extremities of the axis is furnished with two ratchet-wheels *r*, *r*; in the interval of these two wheels there are two others toothed, which enter the axle of the fly by gentle friction; both have a catch *p* placed in the same direction in each of the opposite sides, and in such a manner that they must turn in opposite directions, in order that the catch may act on the ratchet-wheel which immediately touches it: *p*Q is a great rod which slides between two tenons, and being divided into two parts, forms a kind of frame furnished with racks, *f*, *g*, *h*, *i*, which are not in the same plane: *fg* engages the wheel *n*, and *hi* the wheel *m*; if we suppose that the rod PQ moves from Q to P, the rack *hi*, acting on the wheel *m*, by its catch *p*, will communicate to the fly *a* a motion of rotation from right to left, whilst the wheel *n* will turn without impressing any motion upon it. When the rod returns from P to Q, the wheel *n* communicates to the fly a circular motion in the same direction; we may suppress one of the two wheels with its rack, the fly *aa* will not the less continue by its inertia to move in the same direction.

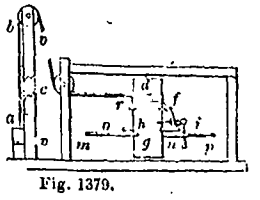


Fig. 1379.

Camus Pile Driver.—The ram *a* is attached to the extremity of the rope which passes over the pulleys *b*, *c*, and envelopes the roller *d*, which with the lever *i*, is the principal part of the machine, whose play depends on the manner in which this roller is joined to the capstan; the capstan and roller have the same diameter and the same axis; the roller should be encircled with iron, with two or more pins of the same material attached to the circle *ef*; the capstan *g* supports the lever *hi*, which has a claw advancing on the roller, and attached to the capstan by a hinge, in such a manner that it may lower itself by leaning on the extremity *i*, and raise itself by means of a spring: this machine is worked by men at the levers *o*, *m*, *n*, *p*, which turn the capstan and roller, fixed to the capstan by the lever *fi*, applied to one of its pins; thus the cord is wound on the

roller, and the ram rises along the post *v v*; when the latter arrives at its greatest height, a man placed at the end *u* of the bar leans on the end *i* of the lever, and lowers it; then the point of the roller escapes the claw of the lever which retained it, and the ram falls; the lever is then let go and raised by the spring, and lays hold of another pin, which joins the roller to the capstan afresh. There is a great friction in this method.

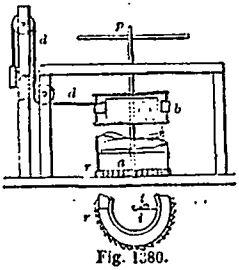


Fig. 1380.

Fig. 1380. is an iron axle, turning always in the same direction, either by the action of men who act on the bar of a capstan, or by the effect of any other mover; it traverses the two wooden drums *a* and *b* which are attached to the axle by gentle friction; the lower drum *a* rests on the plank, and is furnished with two upright surfaces, one outer, the other inner, each making one turn of its circumference spirally; these surfaces are so situated that their extremities are at the two ends of the same diameter; the same drum *a* is furnished with a ratchet-wheel *r*, and a catch which prevents it from turning in the direction of the mover; the upper drum *b* is hollow in its inner part, and furnished with two vertical rods, which carry two rollers, the height of which is equal to that of the lower drum; it is sustained by these two rollers on the inclined planes of the drum *a*, preserving a horizontal position, it also carries a bar of iron *t*, terminated at the height of its lower surface, and its convex surface is cut into a groove to receive the cord of the ram. When the roller fixed on the rods is at the beginning of the inclined plane, the drum *b* is at its maximum of descent, and if the latter is turned in a direction contrary to that of the mover, the roller would meet the two heads of the upright surfaces, and would compel the drum *a* to turn equally, but if *b* turns in the direction of the mover, *a* would remain immovable; and *b* would elevate itself vertically, turning by means of the two rollers to the height of the two surfaces on which it is situated. The iron axis *p* has a strong iron cross piece *i* placed in such a manner that it touches nearly the upper part of the cavity of the drum *b* when the latter is as low as possible. Supposing when the drum *b* is at the maximum of its descent, the bar *i* in contact with, and ready to act on the point *t*; the ram *m* on the head of the piles, and the cord *d* stretched, the axis *p* by its motion will turn *b*, which will elevate the ram to a height equal to its circumference; then the bar of iron *t* escapes the cross-piece *i*, and the drum *b* yielding to the action of the ram *m*, turns in an opposite direction, and allows it to fall, consequently the drum *b* will have an alternate circular motion, while the ram *m* will have an alternate rectilinear motion, and the space which it goes over in this case is equal to the circumference of the drum *b*.

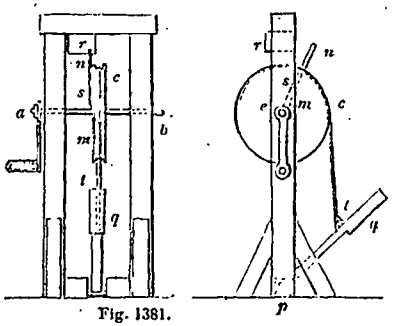


Fig. 1381.

Fig. 1381. *a b* is an axis which the power causes to turn always in the same direction; the wheel *c* acting in a groove, enters into the axis *a b* by gentle friction, but without being able to slide along *a b*, and on one of its faces a pin *s* is fixed: *n m* is an elastic bar fixed to the axle; *r* is an inclined plane placed near the circle *e*, and in the direction of its plane. The cord *c t* has one of its extremities fixed in the throat of the wheel *e*, and the other to the flail *p q*, which turns round its axis *p*. When the axle *a b* turns, the elastic bar *n m* meets the pin *s*, and obliges the circle *e* to turn also, which lifts the flail *p q*. But the bar *n m* meeting the inclined plane *r* retires from the circle *e*, and allows the pin *s* to escape; the circle is then abandoned to the action of the flail, which falls and goes on as before.

It is not possible to describe all the methods by which motion is transformed or converted; to do so, it would be necessary to analyse every species of machine that has been invented: to illustrate the more simple means which have been resorted to, in connecting the first with the second mover of a machine at the impelled point, and the last action upon the working point, is all that we aim at describing; mechanists have devised many ingenious contrivances for particular purposes, but the whole of which it would be impossible to describe.

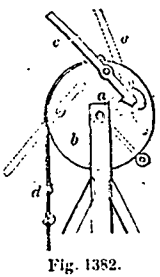


Fig. 1382.

Fig. 1382. is applied to a machine for beating plaster, &c. The piece *a* is fixed to an axle turning always in the same direction, and the wheel *b* is boxed on the same axle with gentle friction, in order that it may turn in contrary directions; this wheel is furnished with a catch *c* to which the piece *a* hooks, which thus causes the chain *d* to mount, to which one of the pistons is attached.

When the extremity of the catch has leaned against the pin or stop *e*, the piece *a* unhooks; the piston suspended to the chain *d* descends by its own weight, causing the wheel *b* to turn.

To change motion at intervals, the Catch-Wheel b, mounted on an axle, receives the motion of rotation by the assistance of a handle.

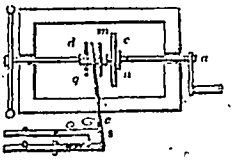


Fig. 1383.

Fig. 1383. *a* is an axle which we suppose to be turning constantly in the same direction by the action of any power: *c* a circle or toothed wheel, which enters the axle *a* by gentle friction, and which has two mortices to receive the pins; *d* is another circle which fits the portion *q* of the axle *a*, which, instead of being cylindrical like the rest of the axle, is quadrangular. In this circle are attached two small pins by means of a fork.

The circle *d* may be made to advance and retreat at pleasure. The machine being in the position represented in the figure, the circle *c* may remain stationary, or may obey the action of the mover, which turns it in a direction opposite to that of the axle *a*. We may regard it as absolutely independent of the motion of this axle, except the slight friction which it experiences towards its centre. But if by means of the fork we bring the circle *d* to the circle *c*, so that the mortices meet the salient pins; the wheel *c* necessarily obeys the action of the axle *a*, until we are again obliged to draw the wheel *d* away, and so on. The spring *e* tends to draw away the collar *d* from the toothed wheel *c*, in order to remove it from the action of the mover; the catch here shown in plan and section turns round the axle *i*; the obstacle *b* on the one hand, the spring *k* on the other, determines the position and extent of its motions; if we turn the lever so that the communication of motion takes place, the catch *s* will be arrested by the spring *e*. When we wish to suspend the action of the mover on the machine, we must press slightly on the extremity *t* of the catch; the spring *e* will act on the extremity of the lever, and the collar *d* will retire from the wheel *c*, on which the mover has no more action. By this mechanism the motion of a machine may be stopped, first at any given hour, secondly, in mills when the corn is ground, thirdly, in looms when the shuttle is stopped in its course.

The first case offers no difficulty; it suffices to make the weight of an alarum act on the extremity *t* of the catch to render it perceptible.

In mills the motion may be stopped when the grain has run out, profiting by the same mechanism as is employed in this case, to call the attention of the miller to remove the catch.

It often happens in *looms for weaving* that the shuttle is arrested by a thread breaking, or some other cause, to prevent the disorder which would result in this case, it must be recollected that when the *batten* is driven from the side of the weavers' beam, on which the warp is rolled, the shuttle is driven by the blow which it receives from the shuttle driver; the batten immediately returns towards the small working beam, to strike the woof, and the batten whose section is given goes with an alternate circular motion over the arc *a b*, whose centre or axis of rotation *c* traverses the sole of the weaver's frame. This motion should not be uniform, but slackened towards the extremity *a* of the arc *a b*, which we suppose to be that on the side of the great beam, to allow the shuttle time to pass from one side to the other to the batten, whatever be the size of the loom, and it should be more or less accelerated towards the extremity *b* of the same arc, to strike the woof. We must imagine an iron rod placed along the batten, and turning freely on the axle *p*, furnished with a bent lever at each of its extremities, and tending by the action of a spring, placed about the middle of its length, to turn in opposite directions, so that the levers resume their original position.

It will be seen that if the shuttle was not arrested in its course, the lever would not meet the obstacles *a*, *c* when the batten by *its circular alternate motion* passes over the arc *a b* to strike the woof; but in the other case, viz. when it is stopped by any obstacle, the lever will then meet the point *a*, which yielding to its action will descend, and acting on the extremity *t* of the catch will separate the collar *d* from the wheel *c*, and in an instant after it will meet the invincible obstacle *b*, the action of the mover will be suspended, and the batten cannot strike the woof; the objects which were proposed will then be answered.

Fig. 1384. is a further modification of the preceding movement. *a b* is the axle which turns in the same direction with the action of the power; the wheel *c* transmits the motion to the wheel *d*, which fits by gentle friction on the axle *e f*; the wheel *d* is furnished with a pin, and the axle *e f* with another *g*; the wheel *d* retires or approaches the pivot *q* at pleasure, by means of the lever *p q*: it will thus be immediately seen that we can stop or produce the motion of the axle *e f* by bringing the wheel *d* near, or taking it away from the pivot *g*.

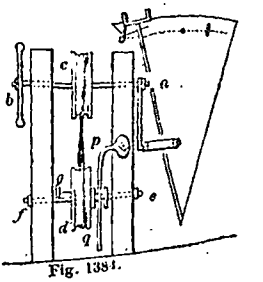


Fig. 1384.

Fig. 1385. Prony's machine: its mechanism only consists of a very ingenious application of

Fig. 1383., by which we can suspend or communicate at

pleasure to a wheel the action of the mover, which causes the axle to turn on which the wheel fits; and reciprocally, we can by this mechanism communicate to the axle, or suspend at pleasure the action of the mover which drives the wheel. Prony caused a great horizontal wheel, *a b*, to turn by the immediate action of the mover; this wheel puts in motion in contrary directions the two vertical wheels *c* and *d*, which work into the horizontal axle *e f*, whose interior faces all engage a ratchet-wheel at *n m*. At one of the extremities of this axle is a pulley, *g*, round which a cord is wound, having a bucket at each end; a piece, *a a*, formed by two iron bars, which carry a ratchet-wheel, *p g*, at their extremities, slides along the square axle *e f* by means of coupling boxes, also cut square; it is evident that if the piece *a a* is pushed towards the extremity *e* of the axle *e f*, the ratchet wheels *g*, *n* will engage, and the axle *e f* will turn in the same direction as the wheel *d*; if it be pushed towards the extremity *f*, the axle will turn in the direction of the wheel *c*, and one of the buckets will ascend while the other descends. Alternate motion is communicated to the piece *a a*, in such a manner that it takes place immediately after the ascending bucket is emptied into the trough, and the cord of the bucket itself determines its motion. For this purpose under the axle *e f* another horizontal axis, *s s*, was placed in a direction perpendicular to *e f*; this iron axle *s s* is furnished with a catch, *x*, which enters the sliding boxes of the piece *a a* by a rod, *h*, terminating by a weight of lead, *p*, and by two claws, *s*, *t*; two knots or forks are placed towards the extremity of the cord above the bucket, so as to engage successively the two levers *m*, *n*. These levers act on the claws *s t*, and raise them, so that the rod *h* passes the vertical position at the moment when the ascending bucket is emptied; then the weight *p* causes the axis *s s* to turn briskly, and its catch *x* drives the piece *a a* towards the same side, and maintains its position, and makes the ratchet-wheels act; the axle *e f* turns in a contrary direction, and so on, &c.

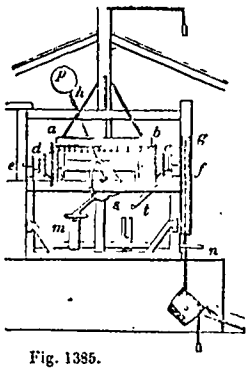


Fig. 1385.

Fig. 1386. shows Prony's method of unharnessing an animal employed to drive this machine when the effort was increased by any cause. Three traces, 1, 1, 1, pass through the openings 2, 2, made in the yoke 4 4, attached to the end of the lever 3; this lever is fixed to the vertical axle, which gives motion to the machine; the openings 2, 2, are furnished with pulleys to diminish friction: the extremity of each trace terminates in an eye, which hooks on to a screw ring, fixed in the axle 5, movable in gudgeons; round this axle 5 is wound a cord, which ascends, passing through the pulleys 6, 6, and attached to a weight along the vertical axle; this weight, which may be varied at pleasure, determines the resistance opposed to the effort of the animal. Supposing the weight limited to 20 pounds, and a stick falls into the teeth of a pinion, it would follow that by the effort of the animal the machine would be broken; but, as the effort will necessarily exceed the weight, which serves as a regulator, the axle 5 will be obliged to describe a quarter circle. The screw bolts having then quitted their vertical position, the extremity of the traces hooked thereto escape, the animal is freed, and the mechanism avoids injury.

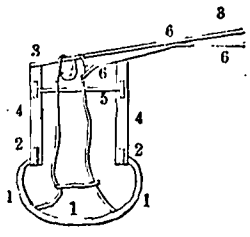


Fig. 1386.

Fig. 1387. *a b* is an axle turning on its axis by means of a power applied at *a*; its pivot *b* rests on a piece of wood *e*, furnished with two rollers, which enter a groove in the cross piece *n m*. By this means the axle *a b* may easily approach successively the toothed wheels *o*, *o*, to which the endless screw *h*, with which it is furnished, engages. *v*, *v* are two cross pieces, which serve to sustain the axle, without affecting the slight balancing motion which ought to be communicated to it by the movable piece *e*, on which its pivot rests. In this piece are two catches, which turn round their two axes, which, as well as the two pins at their extremities, are prolonged; this piece has an axle, having two other branches cut in the form of a fork, to allow the cord which carries the bucket to pass; near the extremity *g* a rod rises, carrying a weight *p*. In the cross piece *n m* are seen two screw rings, *x* and *y*, whose projection equals the thickness of the two catches *a b*, *c d*. Two buckets are attached to the extremity of the cord,

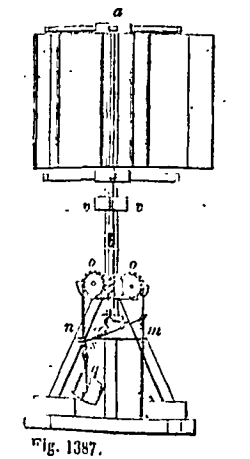


Fig. 1387.

which passes over the cylinder of two toothed wheels o, o, making a turn round each. In the position represented by the figure, the branch u, after having pushed the pin a' towards the left, makes the endless screw h engage the toothed wheel, and the catch $a'b'$, falling by its own weight, engages the pin x, and drives the axle against the toothed wheel. When the button s, which is near the bucket q, has engaged the fork l, the piece u is obliged to turn on its axis, and the arm n, touching the pin b, unhooks the catch, in order to assume a horizontal position; but it has scarcely passed this position when the counterpoise, p, falling on the other side, the arm u pushes the pin, and causes the axle to pass to the right, which engages the wheel o, while the catch cd by its own weight engages the pin y. The two cylinders turn in contrary directions, and the bucket q descends, while the other mounts; the edges of the buckets are furnished with a piece of iron, to oblige them to assume a situation proper for emptying the water. This machine was the invention of M. Belancourt.

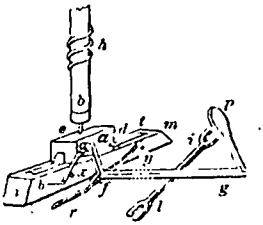


Fig. 1388.

Fig. 1389.—In proportion as the circular motion of the axle ab increases or diminishes, the weights p and q retire from or approach this same axle, by virtue of the centrifugal force; and the crown r, which embraces the axle, descends or ascends vertically. On this crown the motion of a valve m depends, which prevents the steam from introducing itself into the cylinders of steam-engines, or of escaping from them to pass to the condenser, and by this means the machine preserves an almost constant velocity, although the resistance may be variable. We have seen it applied to a windmill to raise the revolving stone when the velocity was too great, to prevent the flour from heating.

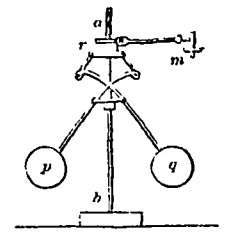


Fig. 1389.

The revolving stone a receives its motion at the upper part, as is the case in all windmills; this stone is carried by the axle, which rests on the sole plate fixed to the bearer. In the axle is fixed the crown fg, which carries four arms to receive the rods of the four iron balls, h, i, k, l, each 4 or 5 pounds weight; from the upper parts of these rods four braces descend, which support the piece m, which slides freely from the top to the bottom of the axle; in this piece a groove is cut to receive the extremity of the lever de, of a forked shape, whose other extremity o supports the bearer, which turns on the centre n; it is evident that by the motion of the revolving stone, the whole system of balls will revolve, and that in proportion as the velocity of the wind increases that of the stone, the balls will fly off from the axle, the piece m will descend, force the lever de into the part d, and will lift the bearer, and consequently the upper millstone a.

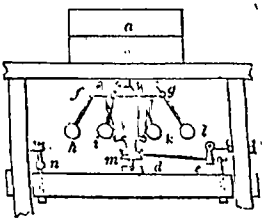


Fig. 1390.

Fig. 1391. *Change of alternate rectilinear motion to continuous circular.* — *Tide Mill.* a is the axle of the wheel turning on an iron pivot or axis; bb are the wings of the wheel, a little inclined, to allow the water to pass in a spiral direction; cc is a drum or circular envelope, in which the wheel turns in the least possible space between its sides and its floats dd, dd. A second drum of a larger diameter is placed above the wheel, and crowns the drum cc with which it is combined; ee are movable doors which open on opposite sides; the first, on the side of the current, opens when it is pressed by it, and is arrested by the post f. The door on the opposite side will be pressed by the current in the opposite direction, and will close. The inverse operation will take place when the water which shall have mounted by the flux attempts to retire at the instant of the reflux. The dotted lines also indicate this contrary motion.

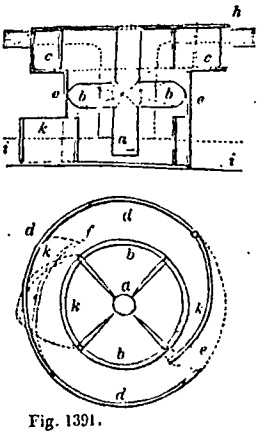


Fig. 1391.

Suppose the surface of a river h, which at low water is level with the cover of the upper drum, in order that the same quantity may always act on the wheel; when the surface of the water is above the circle of the upper drum, the water which passes above will not pro-

duce a greater effect by rising several feet, than when it was at the level of the cover. *i i* shows the bottom of the river, and the water enters the drum by passing the door *e* until it arrives against the post *f*; there it finds a passage, by means of which it arrives at the bottom across the spiral floats, which yield to the impulse of the current, and give a motion of rotation to the vertical axle. When it has arrived at the bottom, the water escapes by the door *k*, producing motion when the tide is flowing out; when, on the contrary, it is coming in, the two doors we have just mentioned close, and the two opposite ones open, by means of which the water descends as before, and turns the wheel in the same direction by the flux or reflux.

The advantages of this wheel over others of the same kind are, that if it be employed for corn mills its velocity is more uniform, since the same quantity of water always acts on it; secondly, it turns in the same direction by the flux or reflux, and in a more simple manner than other tide-wheels; thirdly, as the wheel is horizontal, it is easy to adapt any gear to its axle, since we can elevate this axle at pleasure above the surface of the water; fourthly, the velocity of this wheel is greater with regard to the velocity of the tide, than for other wheels, which dispenses with all the contrivances used in the old wheels to diminish friction; fifthly, it is more economical.

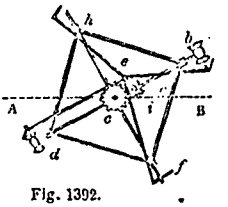


Fig. 1392.

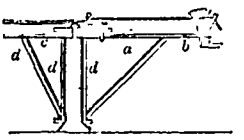


Fig. 1393

Fig. 1392. is a vertical axle, very solidly fixed: it is terminated by a toothed wheel, *c*. A hollow cylinder *d* fits this axle, and reposes in a rebate practised on the lower part of the same axle; four cross pieces *a, b, c, d*, issue horizontally from this cylinder, and at right angles with it; at the extremity of each cross piece is suspended a car; on one of the cross pieces the axle of a small wheel *i* is fixed, which engages the toothed wheel *c*. At the extremity of the small wheel *i* four cords are attached, each passing through a fixed pulley to the extremity of the cross pieces. A person seated in one of the four cars may easily communicate a *continuous circular motion* to the little wheel *i* by means of the cord which passes through the pulley in front of it.

A is a circle whose circumference is furnished with a crown ratchet-toothed; *f, c* two rules which turn freely round the axis of the wheel A; two other rules form an irregular quadrilateral figure with the preceding, whose angles are nearly right angles: the extremities of these four rules are united by axles, round which they turn freely. *h i* is a rule united at *h* with the quadrilateral; an axis traverses at *h* the three rules; the rule *h i* passes through the two tenons *k* and *l*, and can only move itself in the proper direction; two of the rules carry two catches, placed, the one to the right and the other to the left of the figure: these two catches are attached to the rule by hinges, and enter the notches of the ratchet-wheel, either by their weight or the action of a spring: let us now suppose we can move the rule *h i* from *h* to *i*, the catch *m* will act on the crown, and will turn the axle A in the direction indicated by the arrow, whilst the catch *n* will slide on the teeth of the same crown: but if the rule return from *i* towards *h*, the catch *n* will act, whilst the other, *m*, will slide; in both cases the wheel A will turn in the same direction. *The alternate rectilinear will then be transformed to circular continuous.*

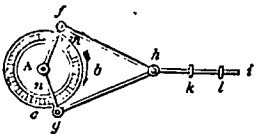


Fig. 1394.

Let *a* be a wheel furnished with six pins; *q p* a horizontal plank sustained by the rollers *b* and *c*, with a catch *d e*, whose length is equal to the distance between the plank and the half of the space which separates the two pins 1 and 2; *f g* and *g h*, forming between them a right angle, this bent lever can turn freely round the axis of rotation *g*: the length of the rod *g h* is equal to the radius of the circle *g*; the point *g* is in the line *g k*, parallel to the rule or plank *q p*, and the rod *h g* tends always to descend by its weight: *f* is a pin which belongs to the plank *q p*; the horizontal distance of this pin from the vertical, which passes through the point *g*, is equal to the distance D*d*. If we make the wheel *a* turn in the direction indicated by the arrow, the pin 1, acting on the catch *d e*, will draw the plank *q p* from *q* to *p*, while the pin 5 will restore the bent lever *f g h*. When the pin 1 arrives at the point *e* it will cease to act on the catch *d e*. The arm *g f* of the bent lever *f g h* will be in a vertical position, and will commence to act on the pin *f* of the plank *h p*, which will return in the direction *q h*; when the pin 5 of the wheel *a* arrives at the point 6, it will quit the arm *g h* of the bent lever, and lean on the pin 4, which

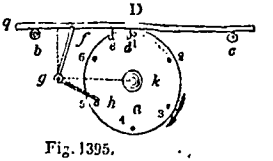


Fig. 1395.

will be found in the place of the pin 5; the pin 6 will occupy the place of the pin 1, and the motion will continue in the same manner, so that at each revolution of the wheel *a*, the plank *q p* will have made six alternate motions: such is the mechanism employed by Thiout for polishing springs.

These two motions give the solution of the problem of the transformation of circular continuous to rectilinear alternate, and have been applied to some steam engines.

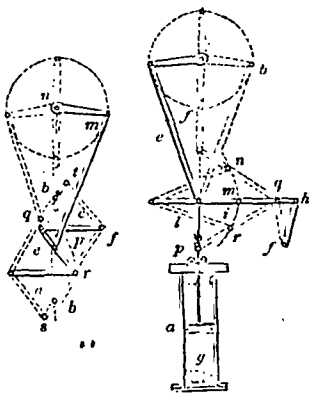


Fig. 1396.

In the first, *n m* is the crank of an axle *n*, which turns circularly by the action of the mover *d* a bar, attached for example, to the extremity *p* of the piston-rod of a pump, and which must go over the line *b b*, equal to twice *m n*: any dimension may be given to the two bars *e* and *c*, and the centre *f* of rotation; *c* must be placed in three positions, *f t*, *f q*, *f r*, which the point *p* of the rod *d* must take up, at the extremities and middle of its course. This will determine the points *q*, *r*, and *s*, where the other extremity of the bar *e* should be in the same line; through the three points the circumference of a circle passes, the radius of which and its centre will determine the length of the bar *a* and its centre of rotation.

In the second we must in like manner have the dimensions of the bars *c*, *i*, and *h*, and the position of the point of rotation *f*: we determine, as in the preceding case, the points *m*, *n*, and *r*; the radius and centre of the circle which passes through these three points will give the length of the bar *l*, and the position *k* of its centre of rotation.

Circular continuous motion with a uniform velocity, or which varies according to a given law, may be changed into a circular continuous, with a velocity of the same nature as that of the motion which produces it, constant or varying according to a given law, in the same plane or in different planes.

The two toothed wheels *a*, *b* engage naturally; the circular continuous motion of the one is communicated to the other in the same plane, but in contrary directions; there must be a third wheel *c* if the motion is to be continued in the same direction. The ratio of velocities will be determined by that of diameters: let *m* be the radius of the wheel *n'*, and *a* that of the wheel *b*: if *m* and *n'* are two integral numbers, the wheel *a* will make a number *n'* of revolutions, whilst the wheel *b* will make a number *n* of its own, in order that the same teeth of the two wheels shall engage, that is to say, in order that the two wheels *a* and *b* should resume the same relative position.

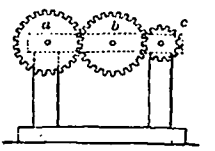


Fig. 1397.

The same problem is resolved by means of a cord or endless chain: the motion takes place in the same or different directions according as the cord envelopes the two wheels without crossing, or crosses in the interval which separates them. Physical causes continually tend to change the length of the chains or cords: to preserve them always equally stretched, springs or counterpoises are employed, but care must be taken to place them in such a manner that the tension produced in the cord turns the wheel on which the mover acts, in the same direction as the mover does the wheel: the counterpoise then produces a very good effect, and may be applied with success to all machines; but if the tension produced in the cord by the action of the counterpoise acts in a direction opposite to the motion communicated by the power, the effect becomes null.

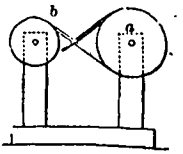


Fig 1398.

There are different means of communicating the motion of one wheel to others employed in the arts, which are combined in the annexed figure.

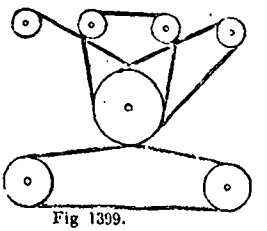


Fig 1399.

When it is required to convert a continued circular motion into another continued circular motion, two things are to be considered, the axis round which the rotation is made, and the velocity, or number of revolutions performed in a given time. If by a rotation round one axis it be required to produce a rotation round another axis parallel to it, it may be accomplished by placing two wheels on the two axes, so that they shall be in the same plane at right angles to the given axes: these wheels may act one upon another, either by the friction of

their edges, or by a strap or chain, or finally by teeth: if they act either by friction or by teeth, the rotation round the two axes will be in contrary directions; but if they act by a strap or chain, the rotation will be in the same direction, if the strap be crossed, but otherwise in opposite directions.

Fig. 1400. represents a watch escapement invented by Breguet to prevent the spring from being overwound or running down to its full extent. In these watches the fusee is suppressed; the barrel A, which contains the spring, has a toothed wheel which transmits the action of the spring to the pinion of the first wheel of the watch; the spring is fixed by one of its extremities to the axle *rd*, and by the other to the inner and concave surface of the barrel. The length of the spring is such that, supposing it entirely unwound, the axle *rd* can make about twelve turns before it arrives at its maximum of tension; in general the mean tension of the spring is only employed, *i. e.* that which results from four turns; the axle *rd* has a ratchet-wheel which prevents the axle from turning in a direction contrary to that which the spring tends to communicate to the barrel. To the axle *rd* a toothed wheel B is fixed, engaging another C, which enters freely in a cylinder rising from the upper part of the drum; a large-headed screw keeps the wheel in its place; the diameter of the wheels C and B are in the proportion of four to five, the wheel B makes four turns, and C five before the same teeth return to the same relative position. Suppose that the spring contained in the barrel A be entirely down, and that the axle *dr* with the wheel B is turned eight times, it will produce the maximum of the action of the spring, and prevent the axle *rd* from continuing to turn. If the distance *de* be divided into two equal parts, and the semicircle *dfe* be drawn, it is evident that the stops to produce the desired effect in the most advantageous manner should be placed in one of the points of this semicircle; another condition is moreover requisite, from the moment that the wheel B is stopped, C turns, impelled by the barrel, and supposing that the proportion of the diameter of the wheel C to the diameter of the wheel B is as n' to n, the wheel C cannot return to the point where it is found after having made a number n' of revolutions round the wheel B, because it previously meets the stops, whatever point of the semicircle *dfe* be chosen for the point of contact; but they will meet under different angles, which does not answer the end proposed. It is necessary that the stops should meet at right angles before the wheel C terminates the nth revolution round the wheel B: let *f* be the point required; the length of the arc *ab* must be equal to the arc *ac*, for if the barrel be turned in the wrong direction, the point *b* will meet and fall off the point *c*, and when the centre *e* of the wheel *c* arrives at *g*, the angle *def* will be equal to the angle *dgf*, and all the conditions will be fulfilled.

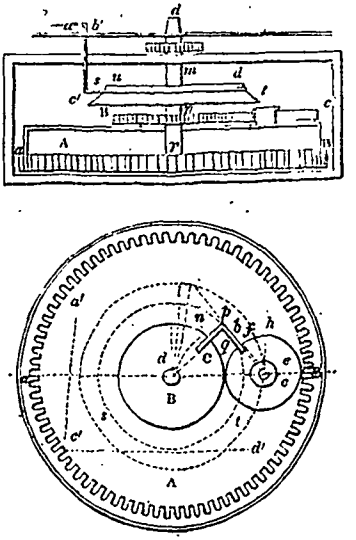


Fig. 1400.

In watches with turning barrels there is nothing to indicate the state of the spring, consequently they stop or are wound up unnecessarily: M. Breguet, to obviate this, cuts the part *mn* of the axis *rd* in a screw fitted with a nut *st* in form of a truncated cone; one or two rods *u* rise above the surface of the barrel, and pass through the nut, without affecting its motion, in the direction of the axis *rd*. When the watch is wound up, since the screw turns without changing its place, and the nut cannot turn by reason of the rod *u*, it moves in the direction of the screw or axle *rd*: while the watch is in motion the nut turns and passes over the same space in the opposite direction; an alternate rectilinear motion is the result, which is transformed to alternate circular by a bent lever $a'b'c'd'$, whose lesser arm $c'd'$ rests on the conical surface of the nut, and the greater arm $a'b'$ marks on the dial plate the tension of the spring.

There can be no doubt that we are greatly indebted to the mechanists, who have applied themselves to the improvement of machinery for the measurement of time: from the period of Richard of Walingford, abbot of St. Alban's in 1326, we have continued to improve in the manufacture of clocks, which perhaps had their origin in the time of Pope Sylvester II., who made one at Magdeburg as early as the year 996. Toothed-wheels were certainly known 1300 years before, as we have them applied to the clepsydra: on Trajan's column at Rome they are also represented, and we are not astonished that, when observed by an intelligent mind, like Gerbert, afterwards Sylvester II., they should be again brought into use. The history of clock-making would afford us the best method

of judging of the progress of machinery; after the balance clock was used in France, about 1370, the most learned men applied themselves to its improvement.

The nature of all the wheels and pinions which are contained between the two brass plates of a clock are highly curious as a machine, the first or great wheel of which in an eight-day clock movement has concentric with it a cylindrical barrel with a spiral groove cut on it: to this cylinder is attached one end of a cord, wrapped round in the groove for any determined number of turns, and to the other end of the cord is hung a weight which constitutes a power or force to set the wheels in motion.

Fig. 1401. represents a machine used in porcelain manufactories for grinding the materials. The power communicates motion to four or six lanterns whose axles descend vertically into a circular tub A A A A A at whose bottom is a stone C, with another, D, laid thereupon whose diameter is greater than the radius of C: the stone D performs the office of a muller, and is fixed to the lower extremity of the axle *a c* by a cramp *e d b c*. The two stones C and D are often advantageously replaced by porcelain plates, but in this case the plate D is loaded with a weight: the materials are put into the tub, which is filled with water; after some time it is found that the stones C and D do not wear equally, the parts farthest from the centre of rotation *c* experiencing the greatest loss, and the two surfaces do not touch at all their points, *f n g m h* remaining hollow. To render these inconveniences less sensible, a little liberty is allowed between the stone D and the cramp *e d b a*, so that as the edges wear it falls, but this only palliates the evil. The stone D can only be made to wear equally by causing each of its points to pass over equal spaces in equal times: to obtain this the following method is employed; the vertical axle passing through the cross piece B B, is supported by a rabbet *n n*, and is terminated by a branch *c b* which forms a right angle with *a b*; from the centre *d* of the muller D a rod *d e* rises, passing through a circular hole in the branch *c b*, and carrying the wheel *e*: the wheel *h* turns freely round the rod *f h*, which rises from the branch *c b*, and is supported by the rabbets in the same rod *f h*: the wheel *g* is fixed to the traverse B B, the axle *a b* passes freely through its centre: the diameters of the three wheels *e*, *h*, and *g* are equal.

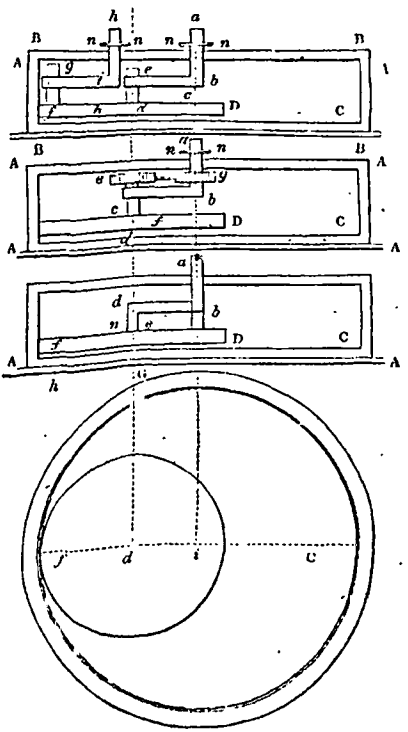


Fig. 1401.

The upper section in our figure represents a very simple method of obtaining the required parallelism. From the centre *d* of the muller D a cylindrical rod *d e* rises, passing freely through a circular opening made in the horizontal branch *r b* of the vertical axle *a b*: from another point *f* of the muller, at a distance *d f* greater than *c d*, another rod *f g* rises, passing freely through a circular opening in the horizontal branch *k i* of the vertical axle *h i*, which is sustained by a cross piece B B; the two branches *i k* and *r b* should be equal. When the axle *a b* turns, the point *d* will trace a circle round the centre *c*, whose radius will be equal to *d c*; the point *f* will have another circle, whose radius *f h* will be equal to *c d*; these two radii will be continually parallel.

Fig. 1403. is a machine for polishing looking-glasses, constructed by M. Sureda at the imperial manufactory of St Petersburgh. The polishers are worked by mechanism precisely similar to that just described: *a b c d* is an iron bar supported by five bent bars of equal length, and disposed so as to be always parallel to each other, while the centre one turns round its axle by the action of the mover. By reason of this motion each point of the bar traces a circle of a radius equal to the length of the elbows, a property which allows of its weight being diminished by sustaining it with cords, *s*, *s*, attached to the ceiling.

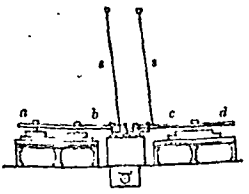


Fig. 1402.

Fig. 1403.

The endless screw, which transmits its circular motion to a wheel; the motion of the mover is perpendicular to that of the wheel; the application of this motion in the arts is innumerable.

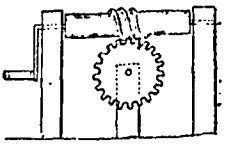


Fig. 1404.

The mill of Piedmont for twisting silk affords a practical example of the application of the endless screw with a great diameter, A B; the single worm of the screw which composes it is divided into six equal parts, all comprised between two parallel planes, represented by the letters *a, b*. The wheel *b* turns by means of six teeth, *c, c*, on its circumference.

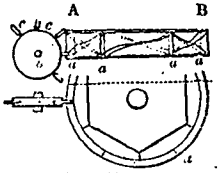


Fig 1405.

The same problem may be resolved by employing a system of wheels placed at right angles, represented by the two truncated cones *a, b*, which are furnished with teeth. This mechanism is often employed; the figure represents one of its most common applications; it is the instrument known under the denomination of *wimble*, much used by carpenters.

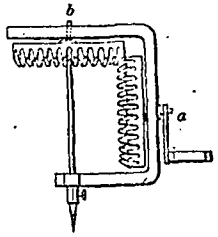


Fig 1406.

a and *b* (fig. 1407.) are two wheels, whose planes are perpendicular to each other, and which communicate their motion by means of an endless cord wrapped round them, and passing over the pulleys *c, d*. The pulley *b* moves from *n* to *o*, turning on its axle: if an obstacle be opposed to the change of movement of its axle, the pulley *b* will turn without changing its position, and the motion will belong to the present class. This motion is employed in mule jennies for spinning cotton.

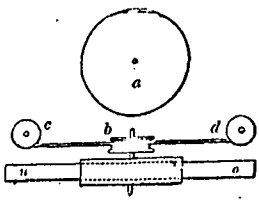


Fig. 1407.

The movements introduced into machinery for spinning cotton, &c. are as numerous as curious: in 1767 Hargrave, of Blackburn, in Lancashire, constructed a machine which enabled him to spin twenty or thirty threads of cotton into yarn at one time, and in 1768 Mr. Arkwright introduced a new mode for spinning, and also a machine for the manufacture of stockings.

Let *ab, cd* be two axles, each furnished with three wheels, *e, f, g, h, i, k*; the two wheels *e, h*, of equal diameter as well as the two *f, i*, and *g, k*, are disposed as shown in the figure; the wheels which belong to the axle *ab* are fixed thereto, those which belong to the axle *cd* fitted with gentle friction, but they may all be fixed at pleasure to the axle by a mechanism before described. It is evident that if we give to the axle *cd* the same velocity as that of the axle *ab*, by making the wheel *b* act; its velocity will be greater if we make the wheel *a* act; it will be less in the same ratio if the wheel *g*, which forms a whole with its axle, acts.

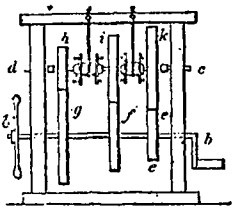


Fig. 1408.

ab, cd, and *ef* are three parallel axes, each of which carries two toothed wheels *g, h*; those of the wheels which belong to the axle *ab*, to which we shall suppose the mover applied, are fixed to the axle, the other fit their respective axles with gentle friction, but may be fixed by methods before pointed out; we suppose the wheels *g* of equal diameter, as well as the wheels *h*, but the diameter of the latter is double that of the former. We may combine this system in four different manners: 1st, if we engage the two wheels *b* belonging to the axles *cd, ef*, with the wheel *a* of the axle *ab*, the two axles *cd, ef*, will turn in the same direction, contrary to that of the mover, with the same velocity, which will be equal to half the velocity of the axle *ab*.

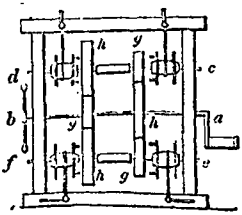


Fig. 1409.

2nd. If the two wheels *g* of the axles *cd* and *ef* engage the wheel *h* of the axle *ab*, the two first axles will turn in the same direction with equal velocities, and twice that of the mover.

3rd. If the wheel *h* of the axle *cd* acts on the wheel *g* of the axle *ab*, and the wheel *h* of the axle *ab* on the wheel *g* of the axle *ef*, the two axles *cd* and *ef* will turn in the same direction, and the velocities of *ab*, *cd*, and *ef* will be in the ratio of 2 to 1 and 1 to 4.

4th. If we make the wheel *g* of the axle *cd* act on the wheel *h* of the axle *ab*, and the wheel *g* of the axle *ab* on the wheel *n* of the axle *ef*; the two axles *cd* and *ef* will turn in the same direction, and the velocities *ab, cd*, and *ef* will be in the ratio of 2, 4, 1.

To transform a circular, continuous, and uniform motion to a circular and variable motion, whose velocity changes according to a given law. This problem may be resolved in a general manner: if we require that an axle D should make a number n of revolutions, whilst another, C, makes another of variable velocities, it is easy to foresee that two points of the two axes should return to the same position after a number n of revolutions of the axle D, or one of the axle C. To simplify the application we shall suppose that the two axles turn in the same time; this case being well understood, the others will not offer the least difficulty.

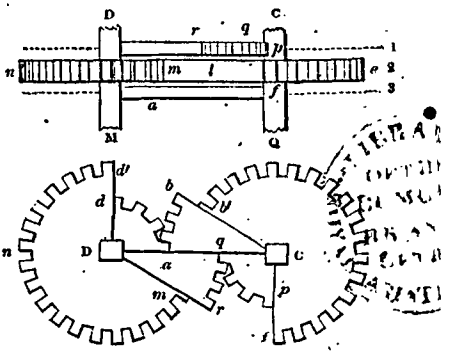


Fig. 1410.

Let C Q, D M be the axles of two wheels a, b; Ca, dD two segments, such that the arc ab is equal to ad, both toothed and placed at the height of the line 1 2; $d'n$, mD two segments of equal radius, so that the arc bcf equals dnm, both toothed and placed at the height of the line 2 2; qCp, qDr, two segments equal to the segments aD D and abC, placed at the height of the line 3 3. We see that by this arrangement the velocities may vary by finite intervals, and in any manner we please, provided the condition is fulfilled of making the points a, a meet at the end of n revolutions of the axles m, n.

The construction of this machine presents some difficulty, on account of the change of gear when it passes from one rate of velocity to another; but this difficulty diminishes by making the teeth very small. In case they cannot be rendered sufficiently short, we must aid the passage by an exterior force, as that of a spring or weight.

We may resolve the same problem by means of two truncated cones, a and b, of equal dimensions, placed as indicated in the figure, that is to say at some distance from each other, their axes parallel, and the small base uppermost, and at the same height as the great base b. A channel is cut, in the form of a helix, in the convex surfaces of the two truncated cones, and one of the extremities of a cord, mn, is attached to the point where the spiral channel drawn on the surface b begins at the great base, and after having enveloped the whole of the same spiral, its other extremity is attached to the corresponding point of the great base at a. It is evident if the truncated cone a turns in its proper direction with a uniform velocity, the other, b, will turn also, but with a variable and decreasing velocity; at first greater than that of a, afterwards equal, and at the end as much less as it was greater at the commencement; the cord nm will then be found enveloping the spiral channel drawn on the surface of a. The motion cannot continue longer in the same direction. If, instead of cutting grooves in the forms of a helix on the convex surfaces of the two truncated cones a and b, we leave these surfaces plain, and substitute instead of the cord nm another endless cord which embraces both, it is evident that this cord may occupy any required place in the height of the cones without its being necessary to change its length.

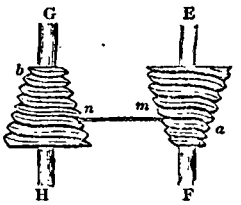


Fig. 1411.

Suppose, first, that the endless cord is placed at the lowest part of the cone; uniform motion of rotation a will communicate to b another of the same kind, but whose velocity will be greater than that of a in a known ratio, a motion which may be continued as long as we please; according as we make the endless cord advance towards the upper part of the cones, the ratio of velocities will diminish; will become equal to unity when the cord shall have attained the middle of the height of the cones, and will follow an inverse course in proportion as it approaches the upper bases.

This mechanism is used with the greatest success to modify the velocities of circular continuous motion, particularly in the lathes used in the manufactures of earthenware and porcelain; the endless cord is made to ascend or descend by means of a jack placed in the midst of the interval which separates the two cones; the rack of the jack is placed parallel to their axes, and directs the course of the endless cord; the mechanism is very simple, and gives instantly all the changes of velocity which can be required.

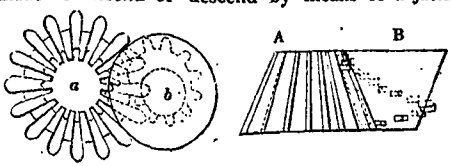


Fig. 1413.

If we suppose that the motion of one of the two arcs mn, qp of the preceding figure is uniform, we may render that of the other uniformly accelerated and retarded, as Roemer has done in the construction of a wheel, proper for explaining the motions of the inequality of the revolutions of the planets; this author supposes a conical pinion a cut in its whole length, as in the figure; its iron teeth engage those of a wheel b, which is also conical; the teeth of the wheel b are placed on its surface in the form of a spiral: and it is useful to observe that the form, the position, and the dimensions of each of these teeth are determined by the form and position of the part of the tooth of the pinion with which they are to engage.

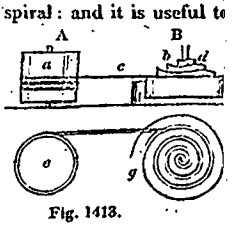


Fig. 1413.

Let a be a drum, b a truncated cone whose contour is channelled into a hollow groove, drawn spirally from the base to the summit, and c a cord whose extremity d is fixed to the cone; near its smallest base, this cord envelopes the channelled groove, and is attached to the surface of the drum. The uniform rotation of the drum would produce a variable motion of rotation in the truncated cone, and reciprocally if the truncated cone turns with a uniform velocity, the motion of the rotation of the drum will be variable. In watches we employ as a mover a spring enclosed in the drum e, which is called the barrel: the truncated cone g is known under the name fusee; round the channelled groove the chain is wrapped, which goes from the fusee to the barrel or drum, and it is by the inequality of the diameter of the spiral that the fusee obtains the property of equalising the unequal force of the spring.

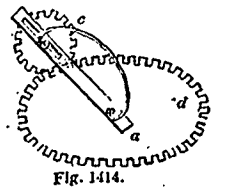


Fig. 1414.

a is a fixed plank: the axle of the toothed wheel c enters the groove mn; the wheel c tends to approach a by means of a spring; d is a surface, for example elliptical, whose edge is furnished with teeth; the uniform circular motion of the wheel c will communicate to the surface d a circular motion which will change its velocity; this method presents the same difficulty as the toothed wheels, and only properly takes place supposing the teeth infinitely small; but we may substitute for them a slightly elastic endless cord, or one stretched by means of a weight spring, not forgetting the observation made on the manner of placing this weight or spring.

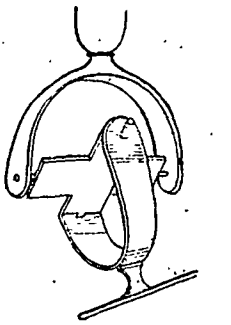


Fig. 1415.

The universal joint, which serves to change the plane of circular motion, is used in astronomical instruments, when the observer, without changing his places, finds it necessary to communicate a circular motion to distant points which are in different planes.

Let ab be an axle which is interrupted by another, which obliges us to prefer this construction to that which we should use if the axle were a single piece: it is required that these two portions should turn as if the axis were continuous; we fix to each part of the broken axle ab a wheel ef of equal diameters; at the side of the axle ab we establish the axle mn in a plane parallel to ab, and at an equal distance from the wheel e and f; in this axle two grooves are cut, c and d, whose planes are perpendicular to the axle mn. The distance which separates them from each other should be equal to the distance of the wheels e, f. Two endless cords embrace the wheels e, f and the throat cd; the two cords should be disposed in the same manner, that is to say, that both should cross or not in the interval of the two axes, in order that the axle mn may transmit its motion of rotation to the broken axle, as if it were entire. But if one of the endless cords crosses, and the other does not, as in the figure, one of the two parts of the axle will turn in one direction, and the other will turn in the contrary direction.

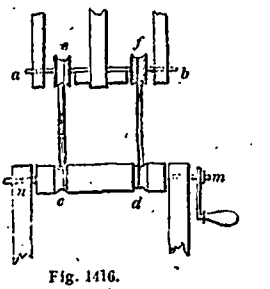


Fig. 1416.

Mechanicians often find themselves under the necessity of employing different means either for regulating the inequalities induced by the moving power, or for guarding machines and men from accidents, sometimes fatal, which take place from too rapid changes of one of the powers acting on the machine. As an example we have fusees in ordinary watches for rendering the unequal action of the spring uniform; the different means employed either for rendering the length of the pendulum constant, which tends continually to vary by the action of the temperature, or for rendering the oscillations of a balance-wheel isochronal. We also have the fly-wheel in bell towers for retarding, by the resistance of its fans against the air, the too rapid motion communicated by the mover, a mechanism also employed in other machines

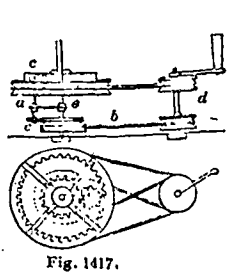


Fig. 1417.

Fig. 1418.

a and b are two wheels of different diameters, as represented in the figure; they fit each other on a common immovable axle, and are in different planes: the circumference of the wheel a is cut into a groove to receive an endless cord, and the wheel b has also its circumference not only cut in the same, but there is also on its surface salient parts, which form a suite of wheels of different diameters, and whose circumferences are grooved: on an axle perpendicular to the surfaces of the two wheels a and b are two others, c. The diameters of these wheels are equal to the difference of the radii of the two a and b; they are placed on this axle in such a manner that the teeth of the one may engage the teeth of the wheel a, and the teeth of the other those of the wheel b. The combination and form of this gear is arbitrary, and depends on circumstances. The rod e is terminated by two rings; the axle which belongs to the two wheels a and b fits one of these rings, and that which belongs to the two wheels c fits the other, which obliges the latter axle always to remain parallel, and at an equal distance from the first: d is a cylinder, to which the mover communicates a circular continuous motion; two endless cords transmit these motions in a contrary direction to the two wheels a and b.

Breguet invented a contrivance for regulating the variable action of the mover in the different parts of a clock, by increasing the friction in proportion as the moving power increases. It was composed of three wheels, a, b, c, mounted on a plate, $eeee$, of two pinions, and a lever d, whose centre of motion, variable at pleasure, was at e; this lever carried at d a pivot of the wheel b, and rested on a round piece fixed at the axle at the wheel c. Supposing the wheel a moved in the direction of the arrow by a variable force, as that of a spring, the greater the force acting on this wheel, the greater effect this wheel would have on the pinion of the wheel b; but as this pinion was carried by the lever d, it carried or drew it towards the point b, and caused its extremity to lean on the round part of the wheel c, whose friction on the pivots was considerably augmented, which tended to diminish the excess of force which the wheel c would have when the spring was unrolled.

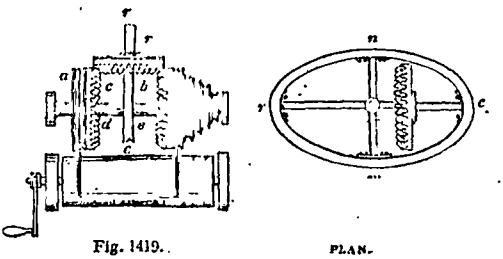


Fig. 1419. PLAN.

Suppose the diameters of the two wheels a and b equal, and we substitute in the place of the two wheels c one whose plane shall be perpendicular to the surfaces of a and b. The wheel c fits the axle r; this axle is pierced with an orifice through which passes the axle de. The three wheels a, b, c are retained in their respective positions by collars made in their axles d, e, r, which prevent them from sliding. The wheel c has two motions of rotation, one round its axle r, the other round the axle de. Let v, v', v'' be the angular velocities of rotation of the wheels a, b, and c. If we suppose that a and b turn in a direction contrary to each other, we shall have $v'' = \frac{1}{2}(v - v')$. We may fix to the axle r a ring $rnem$, whose plane shall be parallel to the wheels a and b, and whose outer edge shall be circular, or of any other form which circumstances may dictate, and which may be traced by the principles before developed; by this means we may transform a circular to alternate rectilinear motion, with any required modification of velocity and direction.

Circular continuous motion with a uniform velocity, or variable according to a given law, may be changed into alternate circular, with a constant velocity, or variable according to a given law, in the same plane or in different planes.

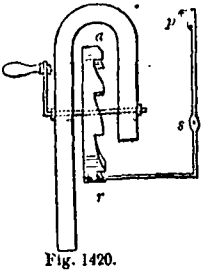


Fig. 1420.

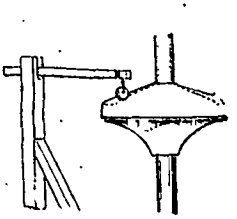


Fig. 1421.

Fig. 1420. a is a wheel whose surface is furnished with wipers, and which communicates a circular alternate motion to the bent level psr. Where there is only one wiper, on the surface of a cylinder may be traced a groove, and by introducing the extremity of two levers, an alternate motion may be transmitted to four pumps at once, making one upward and one downward motion.

We may deduce the means of tracing a curve $a\,m\,n\,p$, cut in a groove, and fixed to a lever $b\,b$, which may turn freely round an axle which traverses its extremity b: if we suppose that the wheel m turns uniformly round its centre, and the pin p, fixed to a point at the surface of the wheel o, enters the groove which forms the curve $a\,m\,n\,p$: this curve may be such that the lever $b\,b$ makes oscillations which fulfil one of the following conditions.

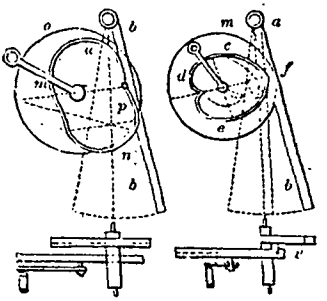


Fig. 1422. Fig. 1423.

First, that the arcs described by any point of the rule $b\,b$ should be described with a uniform velocity.

Second, that the velocity varies according to a given law.

Third, that the arc should not be described, but its chord, which should be gone over with a uniform velocity, or variable according to a given law. The curve drawn in this figure may be traced in such a manner as to satisfy the first of these conditions.

We may also fix the curve $c\,d\,e\,f$ to the surface of the wheel m, so that the circular uniform motion of the wheel m communicates to the lever $a\,b$ a motion of oscillation which may satisfy one of the three conditions just explained in the preceding motion, by means of a pin, p, fixed to a lever which engages the groove. The curve drawn in this figure answers to the first of these three conditions. The means indicated in this article and that which precedes are capable of different applications useful in the arts. The circular alternate motion of the lever belongs to this class; but if it is the chord of the arc drawn on that on which we may fix a rule pierced by a groove, the intersection of this groove by another longitudinal one made in the lever offers a vacant point in which we may introduce a point, which may have an alternate rectilinear motion: the thing will happen if it is the motion of a weight suspended at the extremity of a rule by means of a cord passing through a pulley.

A cylinder, a, furnished with cams, raises the hammer b, which turns on its axle c; this is a well-known motion, and requires no further explanation.

a is the extremity of an axle of a great wheel or fly, furnished with a ratchet-wheel b: $c\,c$ is a wheel which fits the axle of the fly; it carries the catch d, which arrests the ratchet-wheel by means of a spring; the circular alternate motion of the wheel c will transmit to the fly, whose axle is at a, a circular continuous motion in the same direction, but the wheel c will only act during half its oscillations.

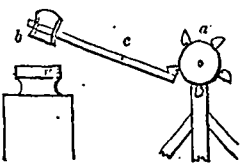


Fig. 1424.

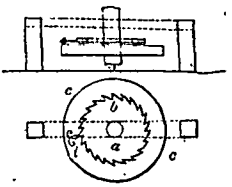


Fig. 1425.

There is another application of the preceding motion; $p\,q$ is a balance beam with a circular alternate motion, which it communicates to the wheel o by means of a cord $a\,b\,c\,d$. It is stretched by the weight e, or by a spring: the wheel o fits the axle h of the fly; the extremity of the axle of the fly is furnished with a ratchet-wheel, to which a catch g hooks, fixed in the wheel o: the circular alternate motion of the wheel o causes the fly to turn in the same direction.

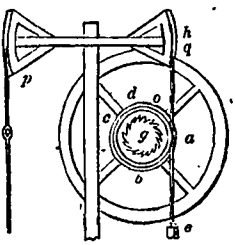


Fig. 1426.

b is a balance capable of an alternate circular motion round the axle c: d is a rod which turns freely on its axle at c; at its extremity is a toothed wheel, e, which engages another, f, fixed to the axle of the fly, n. In the opposite face of the two toothed wheels e and f is a rod, g, which forces the wheel e to preserve this same distance from the centre of the axle of the fly. The alternate circular motion of the balance b compels the wheel e to ascend and descend, but it can only take place when the wheel f turns on its centre; according to the form of the machine the motion may be continuous or alternate, but the inertia of the fly necessarily renders it continuous and nearly uniform; the reciprocal takes place when the motion has begun: in steam engines this mechanism is employed, known by the name of the fly: it may easily be conceived, that notwithstanding the two wheels e and f are of the same diameter, the fly n should make two revolu-

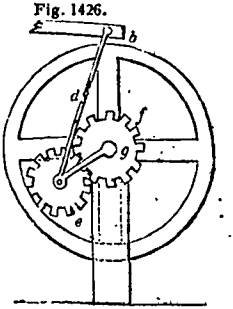


Fig. 1427.

tions for each oscillation of the balance, which enables us to dispense with such flies as the ordinary winch would require to produce the same effect.

We are indebted to Edmund Cartwright for a motion of rotation communicated by steam, whose velocity may be increased at pleasure, without the necessity of any gear-work. The upper part, *a b*, of the frame which embraces the furnace, cylinder, fly, and all movable parts of the machine, are traversed by an axle, on which a pulley, *c*, revolves, round which a chain is wound, fixed to the top of the piston rod *t*. The pulley, *c*, is put into alternate circular motion by the piston and its counterpoise *p*; this axle is armed with a winch, which, by means of a lengthened rod, communicates to a lever *f*, placed horizontally above, on the side of the furnace. There is another axle, placed above or below, or at the side of the first, which traverses the fly *g*, and which is terminated on the other side by a winch, which communicates in the same manner with the preceding by means of the rod, *h*, with the horizontal lever, *f*, just mentioned of. It is evident that

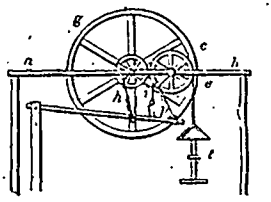


Fig. 1428.

when the pulley, *c*, is put into motion by the action of the piston, *t*, the winch which terminates its axle will move that of the axle of the fly, *g*, because they are both attached to the same lever, *f*. If then the pulley moves in the direction from *a* to *b*, and from *b* to *a*, by the action of the piston and its counterpoise, and if the winch of the axle of the pulley moves in the same direction, that of the axle of the fly will make the same movements, unless its length be so determined that at the end of its course it cannot pass beyond it; the motion of rotation will then take place. If the winch of the axle of the pulley, *c*, is so disposed that when it moves in any space not exceeding a complete revolution, the winch will pass from *e* to *a* by *f*, or in the direction gone over by a given point of the pulley; then the winch will cause the lever to make two vibrations at every stroke of the piston, and at the same time the fly, *g*, will make two revolutions. If the diameter of the pulley is so proportioned that at each stroke of the piston the pulley will make a revolution and a half, and as much backwards, the lever will receive three vibrations by each stroke of the piston. If the diameter of the pulley is so proportioned as to make two backward and forward revolutions for each stroke of the piston, the lever will make four vibrations, and the fly four revolutions.

Ordinary Pedal.—If we suppose that the crank of the fly communicates with the extremity of the lower lever or pedal by an inflexible rod, the ratio between the constituent parts of pedal and their play ceases to be indeterminate, as they are to a certain point when we employ a flexible body. In fact, if we suppose that we have given, first, the length of the lower lever, secondly, its centre of rotation; thirdly, the value of the angle it should pass over at each oscillation; fourthly, the position of the centre of the fly relative to the centre of rotation of the lower lever; the length of the crank, and that of the inflexible rod, are determinate quantities. To find their value, place the pedal, properly so called, viz. the lower lever, in its two positions, the lowest and the highest, and draw two right lines from the centre of the fly to the extremity of the pedal; the first of these two distances is known, and it should be equal to the length of the inflexible rod, minus the length of the crank. The second, also known, should be equal to the sum of these two quantities; consequently the inflexible rod, which should be greater than the crank, is equal to half the sum of the two distances between the centre of rotation of the fly and the extremity of the pedal in its two extreme positions, and the crank should be equal to half the difference of these same distances.

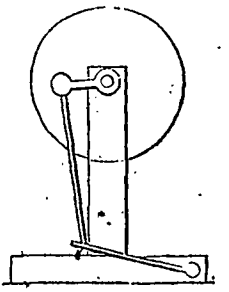


Fig. 1429.

If we suppose the angular velocity of the pedal uniform, that of the fly will be variable in all its points: but these inequalities become less sensible in proportion as the angle gone over by the pedal or lower lever is less, and the greater the distance between the centre of the fly and that of the rotation of the pedal.

Quadrature of the Pendulum, which marks the true time, invented by the Vicar of St. Cyr. The angular wheel *o* carries a curve of equation *bod*; on the breadth of this curve is cut a groove parallel to the edge of the curve; in this groove a button *i* slides, adapted to the piece *ef*, movable at the point *e*; this button also holds a second piece attached to the tube which carries the minute hand *g*, in such a manner that it follows the vibration of the curve over more than half the circumference of the dial minutes, and is sufficient to mark the inequalities which show the equation.

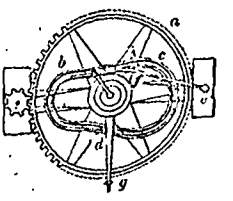


Fig. 1430.

An invention of Breguet as applied to an equation clock, is composed of two parts, one fixed, the other movable. The fixed part is the plate *o*, held by four screws; it is cut out in the form of an equation curve. The movable part is composed of a plate *gg*, having its centre of motion at *c*. It carries a balancing rod, whose centre is at *b*; its two extremities *c* and *d* lean, the one, *c*, against the edges of the curve, the other, *d*, on the prolongation of an indicator or needle *e*, which has the same centre of rotation as the plate *gg*. The prolongation of the needle is maintained against the extremity *d* of the balance, by means of a spring *o* screwed to the plate *gg*; the needle *n* is fixed, and is concentric to the same plate; the movable system is carried by the plate *gg*, which makes a complete revolution in a year. It may be conceived that the needle *n*, which is fixed to the plate, may indicate the days of the year, provided it is placed on a dial divided into 365 parts. The needle *e*, it appears, ought to go over the same space in the same time, which nevertheless is not the case: when the lever *c* leans on the part of the curve most distant from the centre, the needle *e* should be behind *n* a certain number of divisions; when on the contrary the arm leans on the part *m*, which is nearest the centre, the needle *e* will precede *n* by a certain number of divisions. This difference of motion of the needle *n* from the needle *e* is produced by the lever *cbd*, which leans on the curve of the plate *o*, and this curve is such that it causes the needle *e* to gain or lose on the needle *n* by a certain number of divisions, equal to that of the minutes by which the true time differs from the mean time at the date of the days which the needle *n* indicates.

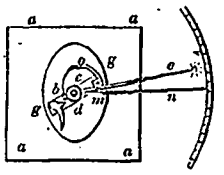


Fig. 1431.

Ratchet Lever, invented by Garousse. The circular alternate motion is changed into circular continuous without the reciprocal taking place: the stirrups *a, b, c, d*, movable on the points *a, c*, are so disposed that the lever, by an alternate continuous motion, forces one to draw the ratchet-wheel continually towards it, whilst the other escapes the tooth it had taken, and engages another. The author applies his lever to a machine for driving four corn-mills at once.

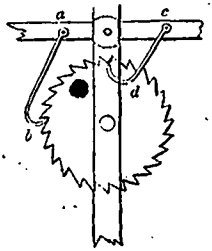


Fig. 1432.

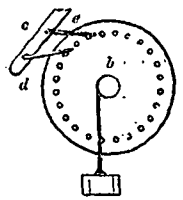


Fig. 1433.

Lever with a toothed Wheel, invented by Garousse; a modification of the preceding. The great lever *a* has its fulcrum at *c*; above and below are two claws or feet *d, e*, movable round their pivots; each of these claws leans on one of the staves of the lantern *b*. The circular alternate motion of the great lever will produce the circular continuous motion of the wheel *b*; if the axle of the wheel *b* be enveloped with a cord, a continuous rectilinear motion will be produced.

b is a species of pendulum attached to a horizontal cylinder, which serves to impress on it a circular alternate motion; the two catches *n, o* are adapted to its surface at its two extremities by hinges, and engage the opposite teeth of the wheel *st*, cut in a ratchet shape, by communicating a continuous circular motion to it, when the power acts without interruption: this has been employed in the construction of a machine for drawing loads: a modification of Garousse's lever, but inferior to it because the power does not act continually, is shown in this diagram.

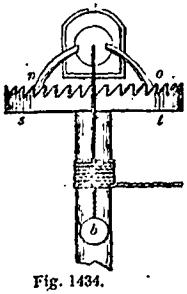


Fig. 1434.

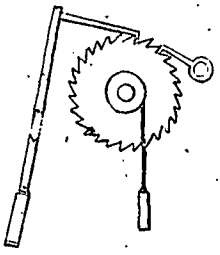


Fig. 1435.

a is a wheel toothed upon its edge, partly horizontal; *b* and *c* are two toothed wheels fixed to the axle *de*; their distance should be equal to the diameter of the wheel *a*. It is evident that the toothed part of the wheel *a*, which is always less than half the circumference, will engage alternately the wheels *b* and *c*, and will communicate a circular alternate motion to the axle *de*.

In calculating the numbers for the movement of machinery, we must remember that a wheel divided by its pinion shows how many turns the pinion has to one turn of the wheel; and in that of a watch, from the fusee to the balance, the wheels drive the pinions, consequently these latter run faster, or make more revolutions than the wheel; but the contrary is the case from the great wheel to the dial wheel.

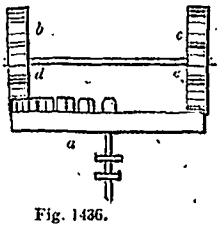


Fig. 1436.

Recoil Escapement, invented in 1680 by Clement of London. The escapement-wheel *b b* receives from the mover a circular continuous motion, which makes the sides of the teeth perpendicular to the sides of the wheel advance, and transmits this motion to the lever or pallets carried by the vertical axle *k*, to which the balance wheel is fixed. The alternate motion or vibration of the balance wheel is here produced by the action of the wheel *b b* on the pallets of the axle of the balance-wheel; they form together an angle of about 90 degrees, in such a manner that when one tooth of the wheel has escaped the pallet *k*, the other pallet presents itself to a tooth diametrically opposite, which in its turn escapes, so that the wheel always turning in the same direction gives vibrations which regulate and moderate the velocity of the wheel *b b*, and consequently of the system.

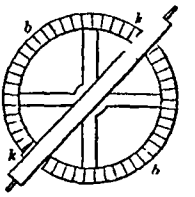


Fig. 1437.

Dead-beat Escapement for Seconds Clocks, invented by Graham. The piece which forms the escapement is like an anchor, but with this difference, that the pallets of the anchor are so constructed, that they do not cause any recoil, and in consequence this escapement is a dead beat, by means of portions of circles formed on the pallets, corresponding with the inclined planes which produce the impulse or action which maintains the motion of the pendulum.

Graham's dead-beat escapement, employed in pendulum clocks, being executed with required care and precision, is one of the most perfect which can be used in these machines, especially by making the pallets of rubies, as some have done.

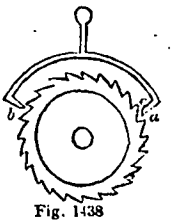


Fig. 1438

The following is the manner in which the escapement acts: suppose the part *a* just escaped, *b* receives the shock of the ratchet tooth; the vibration being finished, the pallet buries itself in the tooth without touching it, the vibration returning; the ratchet wheel remains immovable, and only acts when the inclined plane presents itself to the point of the tooth: for this purpose the tooth acting on the plane obliges the pallet to escape, and in escaping the tooth *c* falls; it strikes the circular part of the pallet *a*, and is retained until its inclined plane presents itself; the tooth of the ratchet then ceases to be immovable, but follows the inclined plane of the pallet, and in escaping restores motion to the pendulum.

Cylindrical dead-beat Escapement for Watches, invented by Graham. *a* is an escapement-wheel furnished with an inclined plane *b*; these inclined planes should be raised on the plane of the wheel; the balance-wheel is carried by a cylindrical axis, one part of which is hollowed, as at *c*; the inner diameter of this hollow cylinder is equal to the length of a tooth, and can turn nearly one revolution round it: it will be seen by this description, that the balance-wheel coming from *a* towards *c*, remains in repose; and when the point *a* arrives at the extremity of the inclined plane *b*, the latter transmits the action of the wheel to the balance-wheel, and leans against the inner part *c* of the cylinder: the wheel still remains in repose; the balance-wheel returns in an opposite direction, again receives the action of the same inclined plane on its leaving *c*, and the following tooth leans on its outer part in the same manner as the preceding, and so in succession.

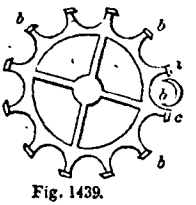


Fig. 1439.

Dead-beat Escapement with Pins, by Ament, Clockmaker at Paris. This is composed of a plain wheel in which a row of pins is fixed; the pin quitting the pallet *a*, that of *b* receives the shock of the escapement: the vibration continuing, the pallet *b* remains still, and the wheel rests immovable, which causes the second hand not to recoil; the vibration returning, the pin acting on the inclined plane restores the motion.

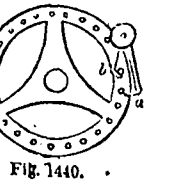


Fig. 1440.

Escapement with free Vibrations, Arnold's Principle. *c* is the escapement-wheel, *d* a cut piece fixed to the axle of the balance-wheel, *t* a small salient point fixed also to the same axle, *n* a spring whose centre of motion is at *r*; this spring tends constantly to approach the wheel *c*, and stops its motion by the salient part *m*: at its extremity a point *p* rises; the spring *n m* is furnished with another, extremely delicate, *s*, whose centre of rotation is at *r*.

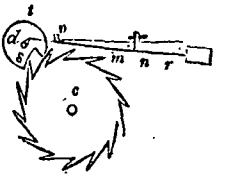


Fig. 1441.

Supposing the balance-wheel turning the point of its axle will meet the extremity of the spring *s*, and will pass beyond, only experiencing a very feeble resistance; but on the contrary oscillation, the spring will meet the obstacle *p*, which is at a very slight distance from its extremity, and instead of bending at *r*, it obliges the spring *n m* to turn round *n*, and

consequently it allows a tooth of *c* to escape; at the same moment another tooth of the wheel *c* strikes the hollow of the piece *d*, and restores to the balance-wheel its lost force; thus at each double vibration of the balance-wheel, the point of the spring *nm* allows a tooth of *c* to pass, and the balance-wheel receives a new impulse.

Escapement with free Vibrations, by Berthond. *a* represents the escapement-wheel, *bc* the catch; the pin of the catch suspends the action of the wheel, whilst the balance-wheel oscillates freely: the spring *d* serves to restore the catch as soon as the pallet *c* has escaped the arm *b*: at this moment a tooth of the wheel *a* acts on the roller carried by the regulator, and transmits its force to maintain the motion of the balance-wheel; the latter having finished its oscillation returns, and in returning the pallet *c* meets the end *b* of the catch; but it yields in escaping this arm, and approaching the centre of the circle most distant from *b*, the spring *e* restores it, to engage it again when the balance-wheel has finished its oscillations, in such a manner that in returning this pallet *c* presents itself afresh to the arms of the catch to disengage the wheel, and give a new impulse to the balance-wheel.

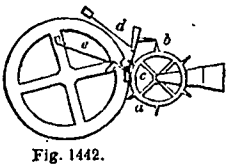


Fig. 1442.

Breguet's ascending Escapement. *a* is a metal plate on which the whole of the escapement is fixed; to understand its mechanism thoroughly, we must divide it into three parts, of each of which we shall describe the separate play, and then their reciprocal action.

First part; this is composed, first, of the wheel *b* and of C, united together; the wheel *b* is submitted to the action of the primitive mover by a system of wheels which tend to turn it in the direction *bcd*. Secondly, of a pinion *g* which engages the stopping-wheel *b*, and which has a number of teeth equal to those of the stopping-wheel, which corresponds to the space between two consecutive teeth of the wheel C; by this means the pinion can, at each of its revolutions, be opposite one of the teeth of the arming wheels: the axis of the pinion carries a fly *tgh*; the branch *gi* of this fly is shorter than the other *gh*, at the extremity of which a small piece of steel is fixed. Thirdly, of a stopping spring *rr*F, at right angles to the direction of the fly fixed at its extremity *rr*, and in which at about two-thirds of its length there is a ruby, V, which may also be made of any precious stone or of tempered steel. In the state of the machine represented in the figure, the ruby leans against the extremity *h* of the fly; it there performs the office of a stop, which preventing this fly from moving in the direction that the pinion *g* solicited, by the wheel B B causes it to turn, thus suspending the revolutions of the wheel, and consequently the action of the mover; but if any cause makes the spring *rr*F to bend on the side of the pinion *g*, at the instant when the ruby V is opposite the notch, which is at the extremity *h*, the fly will escape and make a revolution, and if at the end of this revolution the spring *rr*F has assumed its first position *hi*, it will stop against the ruby V, and go no further.

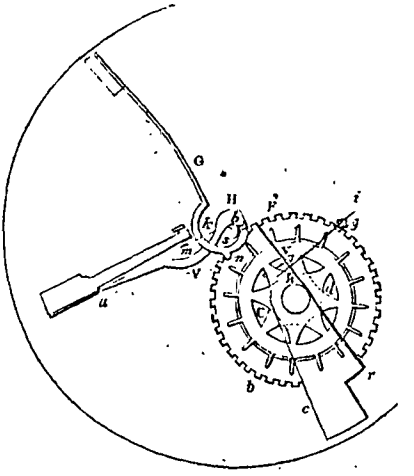


Fig. 1443.

Second part is composed, first, of a spring G of impulse curved at its extremity; this spring is the piece which serves to restore the power to the regulator at each oscillation: it carries a catch or latch *m*, in which is a small notch with a ruby *p* on its exterior surface; this catch and the ruby serve, with the power we have just described, to stop the pulsion-spring when it has been bent by the arming wheel C, which transmits to it the action of the primitive mover. Secondly, of a grappling spring *a*H, fixed at its extremity *a*, on which an extremely weak spring *n* is attached; the spring H carries a ruby *p*, intended to enter the notch *m* of the catch *m*, and to fix this spring when it is on the stretch: another ruby placed on its extremity *s* retains the spring *n* in such a manner, that the end of this spring pressed from right to left opposes only a very feeble resistance, and pressed from left to right gives back to the ruby *s* the whole effort which it experiences, and making the spring H bend, disengages the ruby *p* from the notch of the catch *m*.

Third part consists of the pieces *k*, *b*, carried by the upper extremities of the axle of the balance-wheel, and which are placed at a distance of a quarter of the circle from each other; when the oscillation of the balance-wheel is from right to left, or in the direction *bk*, the piece *k* makes the spring bend and passes beyond; and as the piece *b* is placed above the

plane of the stopping-wheel band, below the spring H, the oscillation from right to left will be easily accomplished, and without any other obstacle than the flexion of the spring *n*; but when the balance-wheel makes an oscillation from left to right in the contrary direction, the pin *k* drives the spring *n* against the ruby *s*, the spring H bends, the ruby *p* disengages itself from the catch *m*, and the spring G, abandoned to itself, produces the effect which we shall now describe.

It may easily be seen by the preceding description how the moving power is restored, and the motion perpetuated: at the instant when the ruby *p* of the spring H is disengaged from the notch of the catch *m* of the spring G, and when this spring G is free, the straight part of the lever *b* is perpendicular to the direction of the motion of the extremity *q* of the spring *g* which has struck it, and also restored to the balance-wheel the force which is necessary to finish its oscillation; immediately after this first percussion the same extremity *q* strikes the end F of the spring F*rr*, bends it, and drives the ruby against the notch of the fly *ik*; the latter then becomes free, and the primitive moving power which acts on the wheel B B, and by means thereof on the pinion, makes it describe a revolution, at the end of which, finding the spring F*rr* at its first place, it again stops against the ruby *v*; but during this revolution a tooth of the wheel D D has pressed on the tooth *n*, which is near the extremity *q* of the spring G, and it has consequently forced it to return backwards: continuing to act according to the proportion established between the teeth of B and D, until the ruby *f* of the spring H is again disengaged in the catch *m*; all then returns to the state represented in the figure.

Another Escapement by Breguet: a is the movable part which tends to go from right to left, in the direction of the arrow; *b* a wheel with six curved teeth, fixed on the same axle with the wheel *a*, but placed at the opposite extremity of the axle; *c* a pinion which engages the wheel *a*, and which should make six revolutions for one of the wheel *a*; *d* a fly which fits the axle of the pinion, and which, by means of a strong spring which presses it, allows it to continue its motion when the pinion is suddenly stopped; *e* a wing or small cross-piece of steel, fixed on the axle of the pinion *c*, and which leans against the stopping-piece *g*, which can turn on the pivot *v*; *h* is the axle, which carries three pieces essential for the escapement: *first*, the piece *i*, which on one side is cut in the form of the curved tooth *k*, and which on the opposite side has two notches to form two ratchet teeth; the first of these two notches serves to stop the motion of the axle, by means of the stopping piece *l*, and the second to give impulse to the pendulum when the axle is entirely free: *secondly*, a pin or small roller, *o*, fixed in the piece *i*, to raise the stop *g*: *thirdly*, a little weight, *n*, which by means of a screw may approach or retire from the axle to regulate the force of impulsion which the pendulum should receive, following the arc which it is required to describe in its oscillation: *l* the stopping-piece, which may turn freely on its centre, which is fixed to the frame of the wheel-work: I I a parabola of the pendulum suspended at its upper part: *m m* a piece of copper fixed to the pendulum bob: M a small light lever, which on one side turns on its pivot *i*, and on the other leans on a pivot *l*; it carries a small salient edge, *m*, which serves to unhook the stopping piece *l*, and to leave the motion of the axle *h* free: *n* is the edge on which the pendulum receives its impulsion; its elevation should be such that it may easily pass behind the stopping-piece *l*, and have a part engaged in the thickness of the piece *c*; its height or lower part should in its motion graze the end of the tooth *f* without touching it. The mover tends to turn the wheel A; the cross-piece E is stopped by the piece F; if we suppose that the bob makes its oscillation from right to left, the salient edge, *m*, of the little lever, M, will touch the end of the stopping piece *l*, and will unhook the tooth *e*, at the same time that the edge *n* presents itself to the impulse tooth *f*. The axle G being entirely free, is driven by the weight of the tooth *d*, as well as by the little weight *h*, to turn from right to left, as its motion is more rapid than that of the pendulum, it arrives at the edge *n*, and gives it an impulse; the tooth *f* elevates itself in its motion: the axle G continuing its motion, the pin *g* touches the tail of the stop F, and leaves the fly D free, at the same time that the tooth *d* presents itself before the tooth *p*, while the fly makes a revolution; the tooth *p* acting on the tooth *d*, conducts the axle D to its first position; the piece F presents itself to stop the fly, and the stopping-piece H enters the notch *e* to stop the axle G; the pendulum going from left to right, finds no other obstacle than the head of the stopping piece H, on which it touches the edge *m*; but being both cut in inclined planes the lever *m* rises, and then falls into its first situation. This is the most perfect manner of re-establishing the force which a pendulum loses in its oscillations.

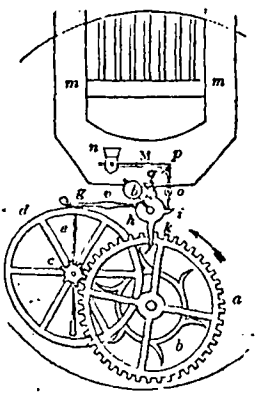


Fig. 1444.

Let de be the crank of the axis of rotation d; this crank is equal to half the chord of the arc $abefg$; an iron rod suspended at f to another fh, which turns round the point h, while the point e of the crank goes from l to e, from e to m, and from m to n; the point f of the rod hf goes from i to f, from f to s, and from s to k: consequently ki should be equal to nl. The shuttle should pass over the arc ab in the same interval of time; the distance ai is divided into two parts, ir and ra; the part fg of the rod efg equal to ri, and another rod gp, equal to ar, which is placed as the figure indicates, in such a manner that its extremities can turn freely at g and p of the rod efg, and of the radius cp of the shuttle; the latter will pass over the arc ab with a velocity whose variations will depend on the ratio between fg and gp.

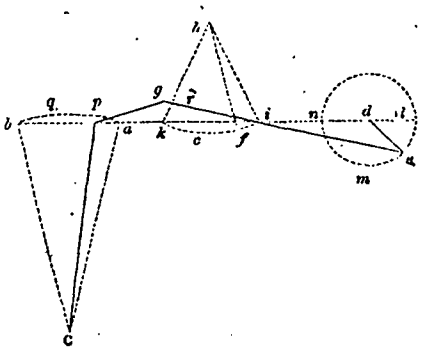


Fig. 1445.

Let ab be an axis which receives from the mover an alternate circular motion; n and m two wheels fixed to the axle ab, both together, but placed in opposite directions; c, d, and e are three toothed wheels, the two first having two equal diameters, which turn freely on the axle ab, and carry the two catches p and q, engage the third e, whose axis is properly supported; the axis ab, by its *circular alternate motion*, will act successively on the two wheels c and d; they will soon assume a circular continuous motion, and as this takes place in opposite directions, the wheel e will always turn in the same direction; thus the circular alternate motion of an axle or wheel may be transformed into a continuous circular motion of another axle or wheel, the second being perpendicular to the direction of the first, and the plane of the second also perpendicular to the plane of the first.

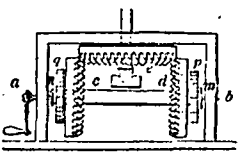


Fig. 1446.

Let ab be the axis corresponding to one of the two cylinders, F or G; c, the counterpoise; no the axis of rotation of the vertical rod, which sustains the counterpoise; q a rod perpendicular to the vertical rod and the axle; tsr the axle of the small machine: nothing is easier, as we have said already, than to cause the rod rs to make a single revolution round the axle de, whilst the axle ab makes any number of revolutions we please: now suppose that the axle rs elevates itself, the counterpoise c would find itself in the vertical which passes through no; an instant after it will fall to p; the motion of rotation of the axle ab will change its direction; the axle sr will also turn in a contrary direction, and meet the rod q above, drawing it from above downwards, and make the counterpoise c pass towards v

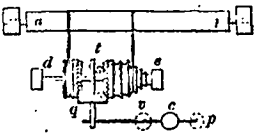


Fig. 1447.

Suppose the axle A B terminated by a square rod, gh, which fits freely an opening made in the centre or the pulley G, sustained by a collar, provided its motion of rotation is not affected; the movable screw m is furnished with a fork or lever, an endless cord embraces the axles m, n, and the pulley G, by means of the pulley H. The circular motion of the axle mn is then communicated to the pulley G, and consequently to the axle A B; this axle in turning will mount or descend freely, if we suppose that the screw m mounts; the lower branch ml of the fork will meet the lever oq of the counterpoise P, and will cause this counterpoise to fall towards the right of the plane of the figure. The axle mn will at the instant take a motion in a contrary direction; the screw m will descend, and the upper branch ik of the fork will meet the lever oq, and acting on it will conduct the counterpoise, and will make it fall on the other side in the time given.

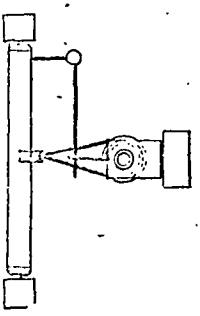


Fig. 1448.

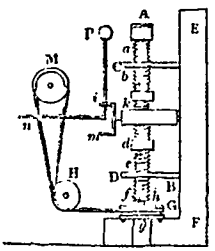


Fig. 1449.

The mechanism may also be employed in the general solution of the problem, without a counterpoise. Let *ab* and *cd* be two axes, each furnished with a pulley and a toothed wheel; an endless cord embraces the pulleys, and communicates the circular motion from one to the other, making them turn in contrary directions, because they cross in the intervals which separate the pulleys. Let *ef* be another axle furnished with a toothed wheel; this axle may approach the axle *ab* or *cd*, because its gudgeons are enclosed in oblong orifices. It will then suffice to bring it near sometimes to the axle *ab*, so as to engage the wheel *c* with the wheel *b*; sometimes the axle C D, so as to engage the wheel *c* with the wheel *b*, to render its motion circular alternate, supposing that of its axle *ab* and *cd* circular continuous.

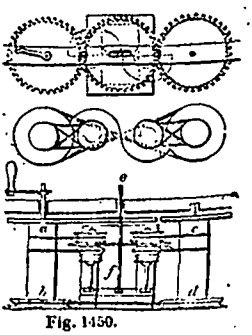


Fig. 1450.

Circular continuous motion with a uniform velocity, or variable according to a given law, may be changed into a motion of a given continuous curve re-entering in itself and closed, with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law, in the same plane or in different planes.

Let *f* be a given curve: it is required that a point of a crayon or any other tool may draw this curve on a surface *pq* by means of the circular continuous motion of the wheel *d*.

Take three toothed wheels *a*, *b*, *c*, of any convenient size: place them as indicated in the figure, that they may receive their motion from that of the wheel *d*: *m m*, *p q* are two rules which move alternately, preserving their direction by means of guides or bridges *c c c*; they are terminated by two perpendicular rules, each pierced with a groove; the crayon or tool which traces the given curve is placed at the intersection of the two grooves. On the given curve take any number of points, which must be most numerous in the places where the changes of the curve are most rapid.

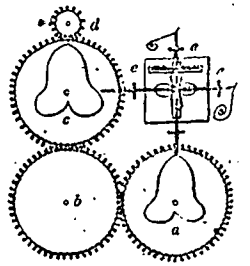


Fig. 1451.

Draw on the surfaces *a* and *e* the proper curves, which should be such that the extremities of the rods lean on the curves, drawn in relief by means of a spring or otherwise: the intersection of the grooves where the crayon is placed goes over the points selected, which operation does not present any difficulty.

The object proposed by this problem is not to make a point, such as the extremity of a tool, go over a certain curve, but to trace this same curve on a given plane surface; for this effect fix the surface *a* to the extremity of the rod *b*. By this means the surface apparently immovable will receive an alternate rectilinear motion; having fixed the crayon or tools to the end *a* of the other rod, *cd*, draw convenient curves on the surfaces *e* and *f*, and we shall have a machine susceptible of useful application in the arts.

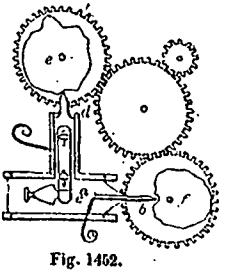


Fig. 1452.

Second general Solution of the Problem. The points of a given curve may also be subjected to angular co-ordinates: these curves are of two kinds, first, those enclosed in the interior, in which we can find such a point that all right lines passing through it can only meet two points of the curve: secondly, curves closed in the interior, in which we cannot find any point which has this property; we can without any difficulty draw curves of the first kind by circular continuous motion. We have in this simple machine an auxiliary wheel conveying its movement to two others on the same axis; the rosette *d* is attached to the first wheel *b*, which touches *n n*, fixed to the regular movement, resting on its edge by means of a spring, *b*, which acts on the extremity of the rule in the movable branch *p q*, and at the point *q* is a pencil, which may be placed at pleasure on any point whatever of the surface on a circle of paper placed on the surface *c*.

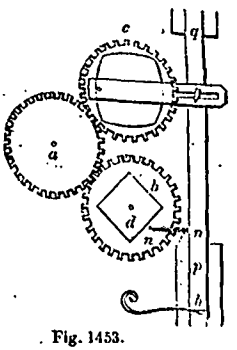


Fig. 1453.

We must always bear in mind that among the machines applied to useful purposes, there is scarcely one in which there is not a deviation from a uniformity of action, either from the nature of the impelling power, or the method by which it is applied, besides a desultory motion, which arises from the construction of the machinery; these peculiarities have been ably noticed by Desaguliers.

Let *a b d* (fig. 1456.) be the given curve, and take in its interior any given point *c* for the centre of the circular motion of the rule *p q*, which turns in the same direction, whilst the

rule ef slides on pq; whilst the point f traces the given curve, the extremity e traces another, abd, and the reciprocal takes place. The length of the rule ef being arbitrary, we may substitute for it the rule $o't'$, and we shall have another curve $a'b'd'$, which also satisfies the condition of the problem: we see that it is capable of an infinity of solutions, all extremely simple: we must take care not to place the centre c in the direction of any element of the given line, to avoid too sudden motions of the rule ef.

The curves of the second kind offer some difficulties. Let a, b, d be the given curves; we do not at first see the general means of satisfying this problem, whatever be the position

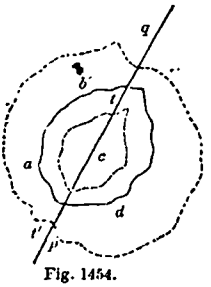


Fig. 1454.

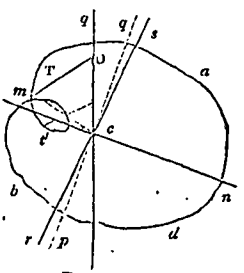


Fig. 1455.

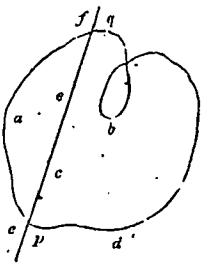


Fig. 1456.

we have chosen for the point c; the circular motion of the rule pq being continuous, while the rule ot is in its direction, its solution becomes impossible; but a very simple observation will enable us to solve it. Suppose O T, instead of being in the direction pq, makes with it a constant angle cot, if whilst pq passes the position $p'q'$ the point o approaches the centre, and places itself at o', the point t will pass to t', and have experienced a retrograde motion relatively to that of pq.

A wheel a conveys its motion to two others, b, c, which in the lathe are on the same axle; the rosette d is attached to the first wheel b, the tool nn is attached to the movable rule pq, leans on its edge by means of a spring b, which acts on the extremity p of the rule, in the movable branch pq, and at the point q is a pencil, which may be placed at pleasure at any point of the surface of a circle of paper, placed on the surface c.

abc is a rule 8 inches long, pierced with a groove, throughout its whole length; the port ab has several screw holes, in order to bring the point b nearer or further, whose head is a screw; this rule is held by the tenons e, g of a second rule; the first may slide on the second, which carries a small barrel, the spring of which always draws the lower rule towards it, which is attached with a pin or fillet d. This same rule carries a second point n, which always tends to approach the centre p; this centre is determined by a third point p, which traverses the two rules, and is fixed to the upper eg, at any point with the screw z.

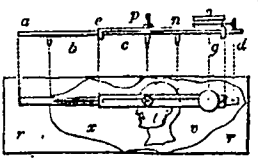


Fig. 1457.

It is required to find the most convenient rosette for the contour of the head t. After having cut out this profile in card, glue it to another card, rr; then take at pleasure any point t for the centre of the contour of the head; pierce the two cards in this point, and attach them to a plane, by driving the point p through; after having placed the point n on the contour of the head, turn the whole machine with the hand, making the point n always touch the contour of the head: or turn the card on its centre, holding the machine fixed with the other hand, taking care that the point n does not leave the edge of the contour.

In both cases the point b on the great card rr, draws the figure x, which is the contour of the required rosette. The point n is always drawn towards the centre p by the effort of the spring, and driven back by the relief of the profile; it easily follows the contour, while it does not leave the centre in a right line, which must be avoided as much as possible, by selecting a centre within the contour for fixing the point p. If we cannot prevent the point h from being arrested at some place, as for example below the nose, and that the contour has the curve too stiff to drive back the point n, it must be aided by the hand; but this inconvenience may be avoided by turning the card in the opposite direction; in this manner the point, which cannot ascend without the assistance of the hand from the nostril towards the nose, will slide without difficulty, and by the force of the spring will be drawn from the point of the nose to the nostril; by changing the centre p, or by taking the two points b and n further off, different contours may be made, the most flowing and most practicable on the lathe, to serve the model for the rosette. Before cutting it out, it is as well to verify it by cutting out in card the figure vx of the rosette, and making the point go over the contour, to see if the other point n will describe exactly the contour of the head t, which it is proposed to execute.

Let an, bc be a system of toothed wheels, whose diameters are in the ratio of the numbers 2 1, 2 4. Let $a'b'$ be a rule, whose extremity a is successively fixed at the points 0, 1, and 2 of the wheel a, and subject at the same time to touch one of the points ac of the wheel n, and 0 and 1 of the line b. These points being placed in such a manner that they may be found in the same direction in one position of the system, each point of the rule $a'b'$ will draw one curve in space, and another on the surfaces of revolution, which are below it.

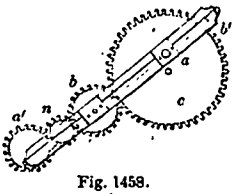


Fig. 1458.

To draw a cylindrical spiral in space, or what is the same thing, to draw the helix of a screw. ab is a fixed axle to which is attached the cylinder c, on the surface of which a helix is to be drawn, and the toothed wheel d. $mlkn$ is a frame turning round the axle ab in its branches; $lmkn$ is an axle fg, which revolves on its own axis, and is furnished with a toothed wheel e, which engages d, and a cylinder, hi, cut into a screw with the nut p, which at one end carries the rod op, whose extremity o enters a vertical g, going from one side to the other of the frame, and the other carries a pencil or tool.

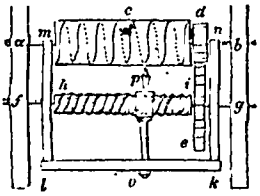


Fig. 1459.

Let a be the radius of the wheel e; b the radius of the wheel d, and d the thread of the screw on the surface of the cylinder hi; if we make the frame $lmkn$ perform a revolution round the axis ab, the wheel e, and consequently the cylinder hi will have made a portion of a revolution $\frac{b}{a}$ round their axes, and the tool will have gone over a space equal to $\frac{db}{a}$, which will be the thread of the screw, drawn on the cylinder c. To this quantity any value may be given, by changing the ratio of a to b, or that of d, by the substitution of another guide hi.

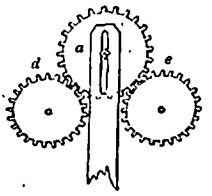


Fig. 1460.

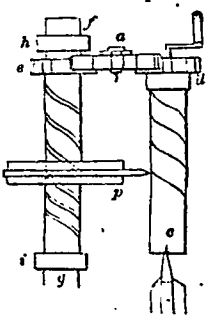


Fig. 1461.

fg is the cylinder which directs the rectilinear motion, and communicates it to the tool, by means of its nut p. It turns on its axle, and its position is determined by the collars h and i; e is a toothed wheel fixed to the directing cylinder, c the cylinder required to be cut into a screw; it is mounted on a lathe, and furnished with a toothed wheel d; the two cylinders c and fg should be placed in such a manner that their axes are quite parallel: a is a third wheel, which serves as an intermediary to engage two wheels d and e; it may be elevated and balanced in order to suit itself to all the changes which circumstances may require in the wheel d to change the ratio of the radii d and e. If the proportion is so great that the invariable space of the machine between the distance of the axes of the two cylinders does not permit us to obtain it by the two wheels d and e, and that it is not possible to change the directing cylinder, we may avoid this difficulty by substituting for the wheel a another wheel and pinion.

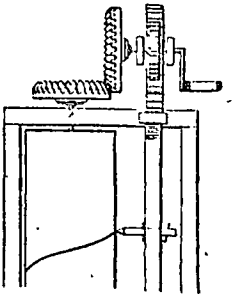


Fig. 1462.

We may substitute for the direction screw a rack whose rectilinear motion may be engendered by that of the cylinder which we wish to cut into a screw; the result will be the same, but perhaps the machine does not combine the same advantages as that just described.

A small machine for drawing an ellipsis. A circular plate of wood a, and of a greater or less diameter, has its surface ploughed by two grooves m, n; in these grooves move easily two pieces b and c; in the middle of each of these pieces a small cylinder or point rises; these points enter circular orifices pierced in the rule bd, one at its extremity b, the other at a greater or less distance from it; we place the pencil at any point of the rule cd, and turn it round its two

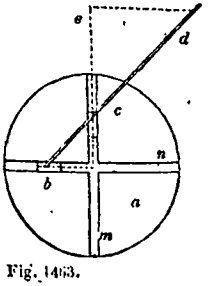


Fig. 1463.

centres of rotation, which move in the same time; the pencil will have an ellipsis whose dimensions and eccentricity we may vary at pleasure.

An Hygrometric Machine. — Suppose that the hygrometric effects act immediately on a rack ab, by communicating a slight alternate rectilineal motion; the axle a is furnished with a toothed wheel b, and a pinion c; it is placed in such a manner that the pinion c engages the rack ab, consequently the slight alternate rectilinear motion of the latter will be transformed into alternate circular, whose effects will be the more sensible, as the diameter of the wheel b is greater than that of the pinion c: the axle nm carries the circle pq, and the latter the index which should mark the degrees of the humidity of the atmosphere, or the hour on a helix drawn on the surface of the column, which should be properly divided: the axle nm has two very distinct parts; one, nr, is cut in a screw, and enters the fixed frame f; the other, rm, is a square rod which slides freely in an opening of the same form, made in the toothed wheel in the centre; this latter engages the wheel b; it is sustained by its edge xx, which rests on the cross piece de; the circular alternate motion of the wheel b will be transmitted to the wheel tu; consequently the axle nm, and the index, will have the alternate compound motion which the proposed object requires.

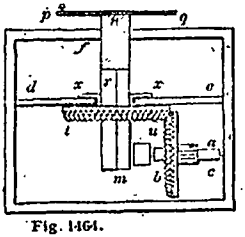


Fig. 1464.

The Geometric Pen is fixed to a table by means of supports, $a, b,$ and c; the heads a, a, of two of these supports, turn round a common axle, in order to be placed in the same plane with the third, and for packing conveniently in a box when the instrument is out of use. At the lower part of the axle d, which is immovable and forms one body with the support c, is fixed a toothed wheel i, which may be changed, but which when it is in its place forms a part of the axle d, and like it is immovable: eg is a metal rule open throughout the greater part of its length, whose extremity e is engaged between the piece k and the wheel i, in such a manner as to turn freely round the axle d: a box b is disposed to slide along the rule eg, and to fix itself in any place; this box carries a second toothed wheel h, which may be changed at pleasure, and which may, according to the place of the box b, engage the wheel i immediately, or receive its motion by the intervention of another toothed wheel, as in the figure: the axle of the toothed wheel h is fixed to a tube i, which belongs to a lower box c; a rule de runs in this box, and carries at its extremity a pencil k, which draws on the paper any required curve; this pencil approaches or retires from the axle of the wheel h, by means of the facility of making the box c correspond to any part of the rule de. It is clear if we turn the rule eg round the axle d, the toothed wheel h will have a total motion of translation round the axle d, and a particular motion of rotation round its own axle; the ratio of angular velocities which these two motions bear will depend on the intermediary toothed wheels, and on the relation between the respective number of their teeth: the box c and the pencil k will have, besides the total motion of translation round the axle d, a special motion of rotation in common with the wheel h, and the curve which the point k will describe will depend on the ratio of the before mentioned angular velocities, and on the ratio between the radii db and bk. These ratios may be varied at pleasure, either by employing different combinations of toothed wheels, or by making the boxes correspond with different points of their respective rules.

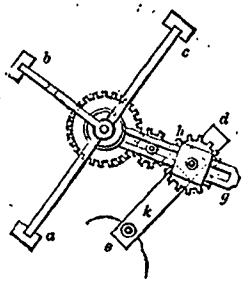


Fig. 1465.

a is a square plate, b a cylinder fixed to the plate a; its circumference is grooved like that of a pulley: cde, fg, are two cords which envelope the cylinder b in opposite directions, and are terminated on either side; at a and d, where they are attached to pins in a fixed rule, and on the other side at e and f, where they are likewise attached to the pins of another rule parallel to the first, which moves freely in the direction of its length; if we communicate to the latter rule an alternate rectilinear motion in the direction of its length, the square a will have a similar motion, but will turn at the same time on the centre of the cylinder b; each point of its surface except the centre will trace an epicycloid: it is applied to polishing glass.

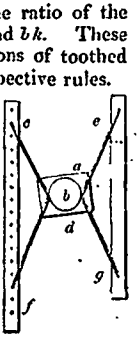


Fig. 1466.

In wheelwork, where the axis is immovable, and the body turns continually in the same direction, each point traverses a complete circle during each revolution of the body round its axis; where this does not occur, the motion is either alternate or reciprocating; where the former is constant and regular, it receives the term of oscillation or vibration.

Fig. 1467. *aa* is a fixed rule furnished with a row of pins, *bb* is a bent axle, *cd* a rule whose extremity *c* is engaged between two pins of the rule *a*, while its extremity *d*, terminated by a ring, enters the bent part of the axle *bb*, in such a manner, that when this axle turns, the rule *cd* has a motion composed at the same time of rectilinear and of circular alternate: by this compound motion each point of the rule *cd* draws a curve, which is more or less of a long heart shape, whose point is always towards the fixed rule *aa*: *n* is a square plate furnished with a ratchet-wheel; this piece may be fixed to any point of the rule *cd*, and ought to turn freely round an axle which passes through the centre of the ratchet-wheel: *fg* is a piece known by the name of wolf's teeth; this wolf's tooth is terminated by a ring which fits the bent axle *b*, traverses another ring *f* fixed at the point of the rule *cd*; and this ring being movable around its axle allows the wolf's tooth to oscillate round the axle *b* in such a manner, that at each turn the wolf's tooth makes a double oscillation, and is terminated at *ik* by a curve constructed in such a manner, that when the extremity *d* of the rule *cd* is in the point of its course most distant from the pins, between which its other extremity *c* slides, the extremity *k* of the tooth will have given to the wheel *n* a slightly circular motion round its centre; after having engaged one of the teeth of its circumference, the same effect should be successively reproduced at each revolution of the axle *e*, by the action of the wolf's teeth on the other teeth of the ratchet-wheels. It is used for polishing glasses.

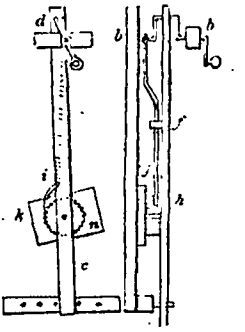


Fig. 1467.

Continuous motion according to a given curve with a uniform velocity, or variable according to a given law, may be changed into a given curve, with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law, in the same plane or in different planes.

Fig. 1468. *Pantograph by Langlois.* — By its means we draw all kinds of similar figures, changing its size at pleasure with velocities whose ratios are given.

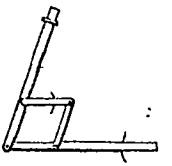


Fig. 1468.

Fig. 1469. Another method: let M G be a portion of the axle comprised between the two puppets *c*, *p*, which it is required to cut; we suppose that the part A G of its prolongation is cut in a screw shape; this prolongation of the axle M G is sustained by the puppet *q*: the screw M G enters the niche S, and cannot turn the rule; A B is conducted by the nut S, which turns freely round the point *a*; it has a horizontal slit *mn*, in which the fixed cylinder *a* enters; the rule C D slides between the openings practised in the three puppets *r*, *p*, and *q*; it carries the tool K, and the perpendicular branch L G, from one of the points of which a small cylinder *a* rises, which enters the slit *mn* of the rule A B: if we turn the axle *a*, the nut *s* will proceed towards G, and will draw with it the bar C D, consequently the tool K will have a velocity which may be varied at pleasure.

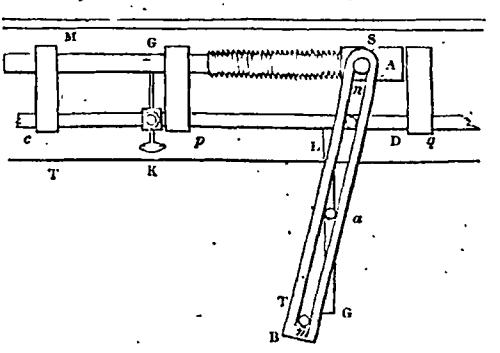


Fig. 1469.

Fig. 1470. *Machine for cutting Screws.* A, the cylinder to be cut into a screw; it is sustained by two puppets F and G; it is terminated at A by a toothed wheel C, and the power which turns it is applied at its extremity A. The axle B is perpendicular to the cylinder A; it is sustained by the two puppets H and I, and carries a toothed wheel D, which engages the wheel C; the part *gh* of

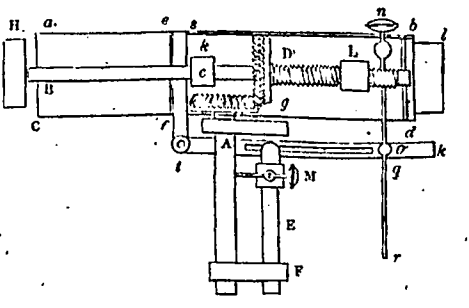


Fig. 1470.

the axle B is cut in a screw shape: E is an iron bar, in which the cutter M slides freely; this bar has the form of a square or triangular prism, it is sustained by two puppets F and G: *abcd* is a large and deep mortice practised on the plane which sustains the puppets F, G, H, I: *efbd* is a rule whose thickness is equal to the depth of the mortice *abcd*; it enters into this mortice, and slides freely throughout its length; from the surface of the rule *ef*, *bd* two puppets K and L rise; the first is terminated by a cylinder pierced with a circular orifice, in which the axle B B enters, and the second by the nut of the screw *gh*: at the extremity *ef* of the rule *efbd* is fixed the rule *esi*; the rule *ih* turns on a hinge round the point *i*, it has a longitudinal slit *lm*, in which a small cylinder enters, which carries the tool M: *p* and *g* are two small spheres which are at the extremity of the two cylinders which rise, the first from the rule *efbd*, and the second from the rule *ih*: these two cylinders turn freely round their axes; the part *no* of the rod *np* is cylindrical and traverses the circular orifice of the little sphere *p*, it can turn freely but cannot slide; the other part, *or*, of the same rod, *nr*, is cut in a screw shape, and enters the nut cut in the little sphere *g*; if the cylinder A A turns, its circular motion will be transmitted to the axle B B, the rule *efbd* will advance, and draw with it a rule *ik*; we may vary at pleasure the inclination of the latter by means of the rod *nr*, consequently it will fulfil the functions of an inclined plane, and will conduct the tool *m* with the required velocity.

Alternate rectilinear motion with a uniform velocity, or variable according to a given law, may be changed to circular alternate with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law, in the same plane or in different planes.

Fig. 1471. *ab* is a lever turning on its axle; the centre of the semicircle *def* fixed to the same lever, at *d* and *f* are the extremities of a chain *dg*, *hkf* fixed to two bolts, in such a manner as to be shortened or lengthened at pleasure; the chain passes round two pulleys *g* and *k*, and the alternate circular motion of the lever *ab* produces an alternate rectilinear motion at the point *h* of the chain. This motion has been applied to a machine for cutting off the heads of piles under water, and is one of the most simple and convenient for this purpose.

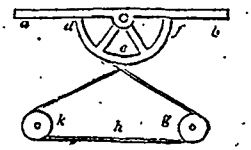


Fig. 1471.

Fig. 1472. The zigzag is a very well known motion requently employed in toys: Du Vivier employed it in a machine for drawing boats out of the water: the nippers for raising heavy bodies from depths is a familiar illustration of it, as is also the common reel or spindle.

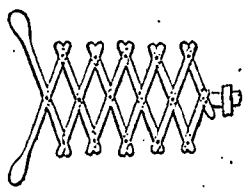


Fig. 1472.

Fig. 1473. is a double suction pump invented by Noble, and first used on board the Windsor Castle, 74 guns, in 1790. It consists of a lozenge formed by four rods *a*, *b*, *c*, *d* of iron, united by a hinge at their extremities, in such a manner that the angles may become acute or obtuse without increasing or diminishing the perimeter of the figure. The plan of the lozenge is here represented vertically, with one of its diagonals in a horizontal position, and sustained by two pillars of equal heights, in such a manner that the same bolt which unites the contiguous sides attaches them to the corresponding pillar; in this position it is clear that the other diameter of the lozenge will be vertical; it should be in the same axis as the pump barrel: at the upper extremity of this diagonal two rods of the lower piston of a pump are attached, and at its other extremity that of the upper piston, and the same bolt which unites the contiguous bars to this diagonal unites them also to the piston rods; since the angles of the lozenge must vary, and with them the length of the diagonals: the two pillars *e*, *e* cannot be fixed; they are consequently placed between two cheeks *c*, *r*, to which they are united by a bolt, and thus have a motion of rotation in the plane of the lozenge.

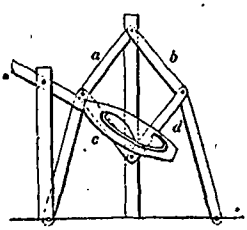


Fig. 1473.

Sometimes it is required to communicate an alternate circular motion, like that of a pendulum, by means of an alternate motion in a straight line: this is done in a remarkable manner in the steam-engine, where the moving force is the pressure of steam, which impels a piston from one end to the other alternately in a cylinder; the power of this piston is communicated to the working beam by a rod connected with one end of the piston. The end of the beam, which has motion communicated to it when united with the rod, draws it alternately to one side and the other, moving in the arc of a circle, the centre of which is that of the beam: this being the case, it is necessary that the rod and the end of the beam should be so connected that, while the one ascends in a straight line, the other shall descend in like manner.

Fig. 1474. By means of two lengths of chain attached in opposite directions to each of the rods m,n passing through the tenons r,r, the circular alternate motion of the balance b, to which the ends of the chains are fixed, communicates an alternate rectilinear motion to these rods.

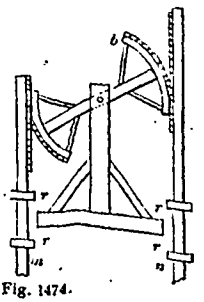


Fig. 1474.

Fig. 1475. is the very well known tool, the common drill: a is the rod, b the cord, c the cross pieces, d the fly, e the muffle or socket, which together are called the stock, g the cutting tool or drill.

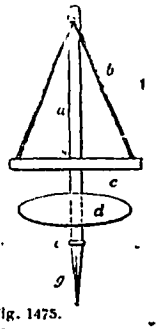


Fig. 1475.

Fig. 1476. is a motion applied to pumps; ab is a rod sliding between the guides c,d: the lever ef turning on its axis g communicates by means of a rod eh its alternate circular motion to the rod ab, which has an alternate rectilinear motion.

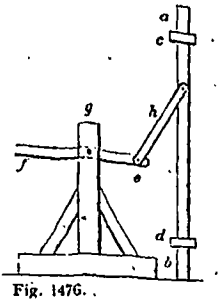


Fig. 1476.

Fig. 1477. Parallelogram employed in double-acting steam engines to transform the alternate rectilinear motion of the inflexible piston-rod to the circular alternate motion of the balance beam: $abcd$ is the parallelogram attached to the beam by the points a and c fixed to this beam, but the sides of the parallelogram can change their inclination with regard to each other by means of their hinged extremities, that is to say, the boxes or collars embracing the horizontal axes: these axes at a and c are in the same plane with the centre or axis of rotation of the beam: the angle d of the parallelogram is always kept at a constant distance from the point e, by means of an iron rod with a box or collar at its extremity, which embraces the axis passing through d.

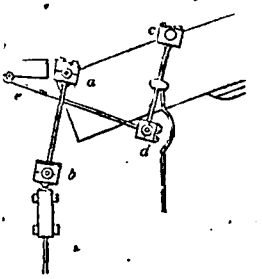


Fig. 1477.

Fig. 1478. The same problem has been resolved by Belancourt without employing a parallelogram: two pieces of wood, ab,do, turn round the points or centres a and o, their extremities b and d are fixed to each other by the iron piece bcd, with articulations at b and d; the lengths ab and do from centre to centre of the gudgeons are equal. The sum $ab+do$ of these lengths is equal to the distance from the point a to the point o measured horizontally, so that when ab and do are level, the right line passing through d and b is vertical; and as the length of the piece bd, from centre to centre of the gudgeons, is equal to the difference of level of the points a and o, bd becomes vertical at the same time that ab and do become horizontal.

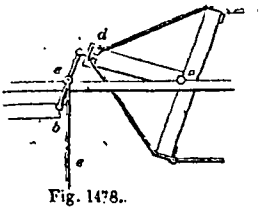


Fig. 1478.

Fig. 1479. The drill bow, too well known to require any explanation.

Fig. 1479.

Fig. 1480. If we cause a wheel a to turn in any direction, the wheel b will turn in an opposite direction, and both will act in corresponding racks, so as to communicate a rectilinear motion to the rod cd.

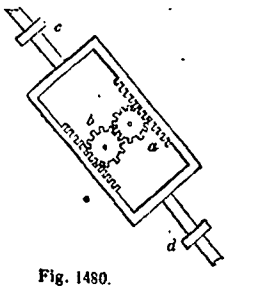


Fig. 1480.

Fig. 1481. is a modification of the preceding, adapted to many useful applications. If on an axis we fix two toothed wheels, and make two racks diametrically opposite engage each of these wheels, the circular alternate motion of the axle will communicate an alternate rectilinear motion to the racks, and the extremities of these same racks will approach or retire from the axle in a uniform manner: it is thus that reels have been constructed, and that we may form a cylinder whose diameter shall be variable as that of which we have before spoken, by multiplying the number of wheels and racks agreeable thereto.

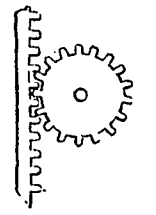


Fig. 1481.

Fig. 1482. To transform alternate rectilinear to alternate circular motion. *abcd* is a rule made to move in a groove, another rule, *tvdkvt*, is attached to the first by the hinge *r* in such a manner, that the system of two rules open and shut round *r*, like the two limbs of a pocket rule; a plate of metal *lmhn*, which moves parallel to the line *bd*, carries two pins *p*, *q*, which lodge in the grooves *v t'*, *v t*, practised in the rule *tvdkvt*. It will be perceived that in virtue of this disposition of the piece *lm*, *hn* moves from the side of *e*; the two rules being supposed open, they ought first to close by the action of the pin *q* on the curve *t' v'*, and then to be drawn by the continuation of the motion of the piece *lnhm*. The inverse of this takes place when the motion of this piece is made in the opposite direction: such is the mechanism employed by M. Droz to put under the die the piece which is to be struck, and to drive away that already struck.

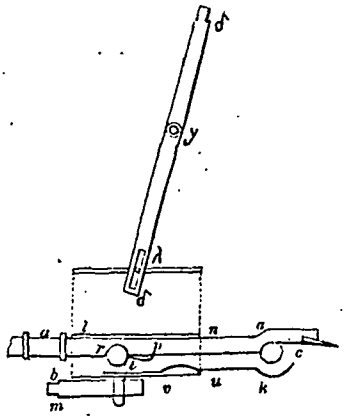


Fig. 1482.

The alternate rectilinear motion of the alternate hand is very slow towards the extremities of its course, and accelerated towards the middle in order to receive the pieces which fall from a hopper, and to deposit them under the die without the least shaking; this motion is communicated to it by means of a pin fixed to the running piece *lnhm*, which enters an oblong opening practised at the extremity of the lower arm $\delta\gamma\delta$; the axis *y* is horizontal and perpendicular to the plane, passing through the axis of the great screw of the die, in such a manner that making this lever move in either direction, we push the pin λ forwards or backwards, and consequently the piece *lnhm*; the upper extremity of the lever $\delta\gamma\delta$ is subjected to move between two curves of metal, constructed according to given rules; each of these curves is attached by its extremity to the axle of the great screw, and they are disposed in such a manner, that the pin λ retires when the great screw lowers, and reciprocally by this we see how the play of the mechanic hand is united with the motion of the die, and what is the result of it; in fact, the circular alternate motion of the die being supposed constant by means of the two horizontal curves which form a groove, in which the upper extremity of the vertical lever $d\gamma\delta$ is transformed into circular alternate, very slow at the extremity of the oscillations, and accelerated towards the middle. The same result takes place for the lower extremity δ, but then we change the planes, and we preserve the same length to the oscillations; if the axis γ is the centre of the lever $\delta\gamma\delta$, we can render them greater or smaller by bringing the upper point nearer or farther.

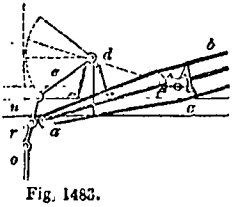


Fig. 1483.

Fig. 1483. *ab* is the beam of a steam-engine, *c* the centre of rotation, *n* a bar of iron which turns freely round an axis *r*, placed at the extremity *a* of the beam, and which divides the bar *n* into two equal parts; the bar of iron *n* is attached at one of its extremities to the piston rod, *o*, and at the other extremity to the iron bar *de*, which turns round a fixed axis.

Fig. 1484. Let *c* be a drum; a gorge or spiral goes from one extremity *a* of this drum, and after a certain number of revolutions terminates at the other extremity *b*; let *fh* be the total course which the carriage must make; take *hg* equal to the height *ae* of the drum A; fix a cord at *f*, and another at *g* both should be of the length *fg*; the other extremity of the first cord is fixed at *a*, and that of the second at *b*, after being rolled in an opposite direction on the spiral gorge of the drum A: these two cords ought always to touch at the same point of the surface of the drum A; according to this arrangement we see, first, if the drum A turns uniformly round its axis, its motion of translation will vary, as the radii of the spiral; secondly, in proportion as one of these two cords unwinds, the other winds, consequently they are equally stretched; thirdly, the drum A will have no tendency to move in the direction of its axis *ac*.

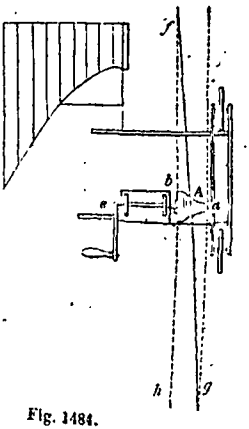


Fig. 1484.

This latter circular alternate inconstant motion is changed into alternate rectilinear, following the law which the end of the machine requires.

Fig. 1485. Camus describes machines which he has invented for making several sieves go at once; that which the figure represents reduces itself to a great table *a*; above this table is a plank *bc*, sustained by two iron axles *n*, *n*, which turn on two supports of the same metal; these supports being fixed to the table on the prolongation of one of the axles, or on a rod, which is in their direction on the plank, is fixed the pendulum *rs*, and consequently communicates also an alternate circular motion to the plank *bc*; its edges strike against the table *a* at each oscillation, and imitate the vibrations or strikes which workmen give to sieves.

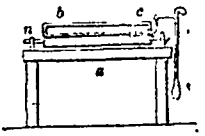


Fig. 1485.

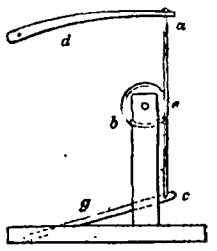


Fig. 1486.

Fig. 1486. The cord *abc* is attached at *a* to the spring *d*, turns round the cylinder *e*, and is fixed at the extremity c of the pedal *g*. The circular alternate motion of the pedal communicates another of the same nature to the cylinder *e*.

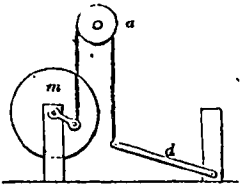


Fig. 1487.

Fig. 1487. The circular alternate motion of the pedal *d* produces circular continuous in the fly *m*, and circular alternate in the cylinder *a*.

Fig. 1488. Nippers for cutting off the heads of piles: these consist of two pieces of iron, *abcd*, *efgh*, which turn round the axle *i*, the extremities *ab*, *cf* of these two pieces are cut into a semicircular form, in order the better to attach themselves to the pile to be cut off, and their whole forms the beak of the nippers. The other extremities *bcd*, *fgh* of these same pieces of iron are terminated in two portions of arcs of circles, *dc*, *gh*, the first furnished with teeth in its convex, the other in its concave part: at the half of the interval which separates the two arcs of circles, *dc* and *gh*, an axle *s* rises perpendicular to the plane of the nippers; this axle carries two pinions, *n*, *m*, which engage, the first with the teeth of the arc *dc*, and the second with the teeth of the arc *gh*; the circular alternate motion of the axle *s* will open or shut at pleasure the beak of the nippers.

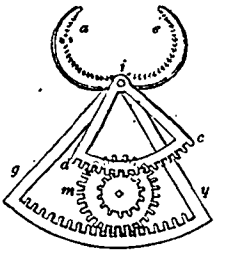


Fig. 1488.

Fig. 1489. A long bar or beam *ab* is traversed in its centre by an axle which is at the upper extremity of an upright post *cd*. The circular alternate motion communicated to one of the extremities of the bar *ab* by the action of a person seated at this point, and who tends alternately, sometimes to elevate himself by forcing his feet against the pavement, sometimes to descend by his own weight, communicates the same motion to another person seated at the opposite extremity.

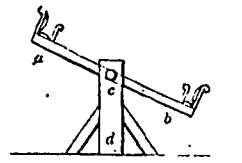


Fig. 1489.

Circular alternate motion with a uniform velocity, or variable according to a given law, may be transformed into alternate in a given curve, with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law in the same plane, or in different planes.

Fig. 1490. Lathe without an axle for making all sorts of screws, invented by Grandjean. This lathe is composed like common ones of a bench and two puppets, *p*, *o*; these puppets have, instead of points, two collars, *s*, *t*, to receive the axle *fh*, terminated in a point at its two extremities; this axle carries the piece *r* required to be turned, and the pulley *g* which receives the cord *go* attached to the treadle *o*; the puppet *a* carries an iron support, *i*, to which is attached at *i* an iron square *hik*, one extremity of which leans on the point *h* of the axle, which it tends consequently to press from *h* to *f*; the other extremity leans on a piece *e*, movable on an axle *d*, at the extremity *d* of which the piece *dc* is mounted on a square, in the groove of which slides a box *d*, to which is attached the cord *no*, which is fastened to the treadle *o*; it is evident that by leaning the foot on the treadle we not only shall turn the axle *fh*, but also lower the piece *dc*, which causes the axle to advance from *f* to *h*, by a quantity reciprocally proportionate to the distance *dn* of the box *n* to the centre *d* of motion; and as the piece *n* is movable, we may place it

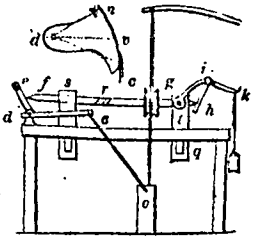


Fig 1490.

wherever we judge fit; whence it follows that during a revolution the axle will advance any quantity we require, and consequently, placing the tool at z, we can cut a screw of any size we please. If we wish to turn a screw whose threads continue to contract, we may do it easily by means of this machine; for this purpose we have only to take off the piece cd and substitute dnc, whose circumference nvc, in the groove of which the cord at n passes, is a curve whose radii dv, dc increase in the same manner that we wish the helix to diminish; for this purpose each point, c, v, n, of the curve will successively perform the duty of making dn of a different length, which can only be done by making the axle recoil unequally towards h, in order that the threads of the screw should not be unequally cut in the portion of the radii dcd, vdn.

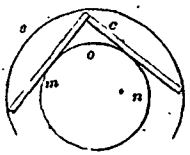


Fig. 1491.

Fig. 1491. Clairault has proposed the problem of finding the curves m, o, n, round which, if we make the square mcn slide, its summit c will always be in the curve ec. We give to the square the motion that this problem requires by circular alternate motion, which we may transform into alternate in the given curve ec.

Fig 1492. a, a are two uprights, which rise from the beam b perpendicularly; the cross piece cc ties together the two upper extremities of these uprights; these four pieces form a frame, whose vertical position is secured by the other pieces d, and dg is a cylinder furnished with a toothed wheel h; i is a pinion which engages the wheel h; the axle of the pinion carries a winch at the extremity, to which the mover is applied; $abcd$ is a carriage which slides downwards between the two uprights a, a; two cords e, e fixed to the upper cross piece of the carriage pass through two pulleys which are attached to the head c, and roll on the cylinder g; another cord f is attached to the middle of the lower cross piece of the carriage, passes through a pulley fixed to the beam b, and rolls on the cylinder in a direction contrary to the two preceding: the carriage $abcd$ carries an iron cylinder; the extremity of this cylinder rests on an iron cramp in the centre of the upper surface of the lower cross piece of the carriage, passes through an orifice made in the middle of the upper cross piece, and is terminated at h by a borer or other utensil. The cylinder of iron is furnished with a pulley m, about the middle of the distance, which separates the two cross pieces of the carriage; a cord $nopq$ fixed to the head c at n passes through the pulley o, which is in the middle of one of the vertical sides of the carriage, envelopes the pulley m, round which it makes an entire turn, then passes through the pulley p, which is in front of the pulley o, on the opposite side of the carriage, or which rises from the lower cross piece to a convenient height, and is terminated at q, where it sustains a weight h, which serves to keep this cord in a degree of constant tension. If the mover acts by a circular alternate motion, this motion will be transformed into rectilinear alternate by the means already indicated. The iron cylinder gh will participate in the alternate rectilinear motion of the carriage $abcd$, and at the same time will have a circular alternate motion produced by the constant tension of the cord $onpq$. The combination of these two movements will make the utensil perform a spiral; such is the mechanism employed in the royal manufactory of arms at Versailles for rifling the bores of fire-arms.

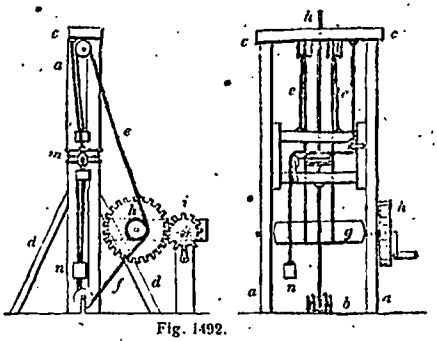


Fig. 1492.

The alternate motion according to a given curve, with a uniform velocity, or which varies according to a given law, may be changed into alternate motion according to another given curve, with a velocity of the same nature as that of the motion which produces it, constant or variable according to a given law, in the same plane or in different planes.

We transform alternate given motion into circular continuous by the means indicated already, and the latter into alternate.

So numerous are the contrivances for modifying motion, that we can scarcely define the hundredth part of those introduced into our complex machines, many of which are as conspicuous for their elegance as for their simplicity. The varieties which most commonly present themselves are, however, divided into rectilinear or rotatory: in the first we have seen the several parts of the moving body proceed in parallel straight lines with the same speed; in the latter, the several points revolve round an axis, each performing a complete circle, or similar parts of a circle in the same time; each of these varieties are again resolved into continued and reciprocating, so that we have four principal species of motion in ordinary use for the transmitting motion.

CHAP. XII.

MACHINES, TOOLS, ETC., ETC., EMPLOYED IN CIVIL ENGINEERING.

Machines for raising weights, or removing them, are principally levers, capstans, wheels, pulleys, inclined planes, screws, and their various combinations in the form of cranes and derricks. Wheelwork is now employed in a variety of instances, its power in all cases being derived from the same principles as the lever, each wheel and pinion being considered as composed of a series of bent levers, of which the axis is the common fulcrum, acting in succession on the teeth of the next wheel.

The Lever is the most simple and the most generally useful for raising weights to a small height, but the extent of its action is still limited, although we are indebted to Perrault for an invention which has greatly increased its power; two pins are fixed in the lever at a short distance from each other, which slide in two pairs of vertical grooves provided with ratchets, so that when the long arm of the lever is pulled by means of a rope, the nearer pin serves as a fulcrum, and the more distant one is elevated at the same time with the weight, and detained in its place by the click; when the rope is slackened, the weight sinks a little, and raises the pin, which first served as a fulcrum, to a higher place in its groove.

A Winch with an axis is a bent lever, and often used as a power, to draw water from a well; a vertical axis, with two or more levers inserted in it, constitutes the capstan; to estimate their force all that is necessary is to add to their radius half the thickness of the rope, and compare it with the arm of the lever.

The Gin for raising coals and other weights is an erect axis or drum, turned by the force of horses working in a circle. The buckets are attached to the opposite ends of a rope, passing round a drum, to which it is drawn by its property of adhesion: one bucket descends empty, as the other rises full, and when the motion of the buckets is required to be changed, the horses are turned, or the wheels are made to impel the axis in a contrary direction, when any other moving power is employed.

The Capstan is not supposed to have been much employed in Britain previous to the sixteenth century: at its first introduction it consisted of an upright barrel or drum, turning on a vertical axle; at the upper part was the head, in which were holes or sockets for the insertion of the eight levers or bars, which were from ten to twelve feet in length. The action of the men employed to turn it round was necessarily constant, for if left an instant, the weight would immediately run back or recoil.

An improvement in the method of pulling the capstan was first made in France by Lalande, who contrived the palls, now attached to the lower parts of the barrel, which turning on a pivot raise the capstan, and press it forward over any obstacle, when they fall by their own weight into iron steps made to receive them, which in case of any recoil also check the descent of the weight; when the motion is to be reversed, the palls are turned over on their pivots, and they act in the other direction.

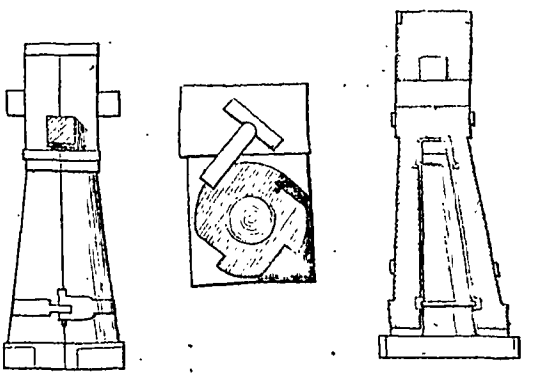


Fig. 1493. CAPSTANS.

There being some difficulty in surging the rope on the plain cylindrical barrel, it was furnished with additional pieces securely attached, and called whelps; to which, as well as to the barrel, the capstan head is bolted down; they are slightly conical, for the purpose of allowing the rope to be received and delivered without rising or falling from its proper place. The power of such capstans depends upon the length of the lever or bar, or the distance of the centre of pressure on the bar, and on the radius of the barrel, including the whelps, and half the thickness of the rope.

The power with which a man pushes when working a bar, multiplied by the distance from the axis, expresses the effect of this power; when there are several, the power must

be multiplied by the number, which is equal to the weight multiplied into the radius of the barrel.

Power Capstan has a compound barrel, consisting of two cylinders of different radii; the rope is fixed at the end of the largest, and after passing over the pulley, which is attached by the hook to the load to be moved, it is coiled round the other cylinder, and fastened at its upper end. By means of the bar at the two ends, the barrel is urged about its axis, so that the rope may coil round the large cylinder, whilst it unwinds itself from the smaller. Supposing the diameter of the one to be 21 inches, and the other 20 inches, it will be evident that one turn will gather 63 inches in one cylinder, whilst 60 inches will be uncoiled from the other; the quantity of wound rope exceeds the quantity unwound by 3 inches, the half of which space will be the distance through which the pulley moves by one turn of the bar. By a common capstan of the same dimensions the length of rope coiled round the barrel by one revolution of the bar would be 60 inches, and the space described by the pulley or load half that amount.

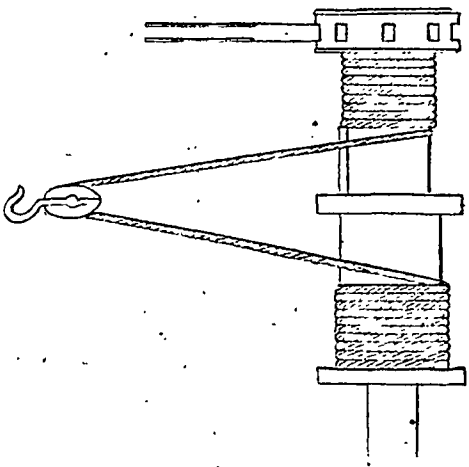


Fig. 1494. ECKART'S POWER CAPSTAN.

The power of such a machine is equal to the velocity of the impelled point, divided by the velocity of the working point; or to the velocity of the power divided by the velocity of the weight.

The lever, then, on the two capstans of similar diameters will exert a power as $1\frac{1}{2}$ to 30, that is, inversely as the velocity of their weights, and the power of one will be $\frac{30}{1\frac{1}{2}} = 20$, or equivalent to twenty fold tackle of pulleys.

To double the power of the machine it is only necessary to cover the small cylinder with a thickness of a quarter of an inch, making the difference between the radii of each half what it was in the first instance; the power of this capstan increasing as the difference between the radii of the cylinder is diminished. Such a capstan is often used as a windlass for raising weights, and a winch applied instead of a bar to turn it; it has the advantage of not requiring a ratchet-wheel and catch to stop it, as the two parts of the rope pull on contrary sides of the barrel; the rope which coils round the large barrel acts with a larger lever and with greater force than the other, but not sufficiently to overcome the friction of the gudgeons, so that the weight remains wherever it has arrived.

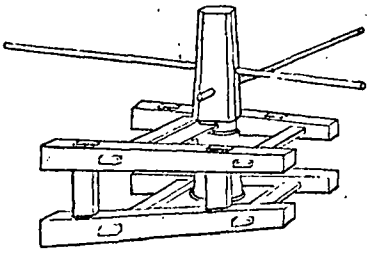


Fig. 1495.

When the anchor of a ship is weighed, the cable itself would be too large to bend round the capstan; it is therefore connected to an endless rope called a messenger, which, as it coils round the lower part of the capstan, quits the upper, so that its place becomes lower and lower, till it has no longer room on the capstan; and it is necessary to force it up from time to time, which is called surging the messenger. This is done by beating it; to add to the facility of the operation, the capstan is made conical, which enables the rope by its tension, when guided by a pulley, to bring the messenger into its proper place.

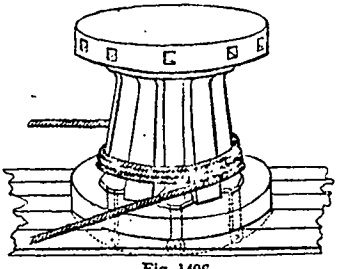


Fig. 1496.

In the common windlass the power is applied by means of a winch, which is a rectangular lever; in other cases no wheel is attached to the axle, but it is pierced with holes directed towards its centre, in which long levers are introduced, and a continuous action produced by several men working together, so that while some are changing the lever from one hole to the other, the rest are turning the windlass.

A modification of the above capstan consists in applying two cylinders in a vertical position, around the larger of which the rope coils, as the handspikes applied to the smaller made to work in a frame turn it. When two cylinders of different sizes revolve on the same axis, and the weight is wound round the larger, its operation is very powerful, as we have previously shown.

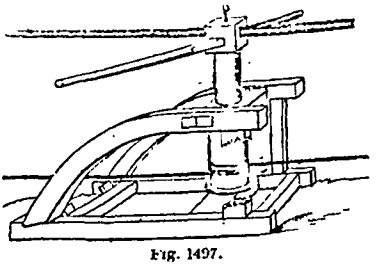


Fig. 1497.

The capstan made use of on wharf walls or in docks is usually of iron, with a shaft of considerable length, turning on a pivot at the bottom of a brick or stone chamber constructed to receive it: at the top of the chamber is a capping, which guides the motion of the capstan as it is turned round by a handspike or lever applied at the top.

The manner of applying the pulley to two cylinders of different diameters on the same axis is very simple; the rope is made to pass from the smaller one, over a pulley connected with the weight, and returns again, to be wound up by the larger one; a considerable length of rope is required for a small extent of motion, but the action is one of considerable power.

One of the most curious applications of the capstan was made by the Count de Carbury, when he moved a mass of granite to St. Petersburgh for the pedestal of the celebrated statue of Peter the Great, which was estimated to weigh upwards of 1500 tons; its dimensions being 42 feet 6 inches long, 26 feet wide, and 23 feet high. This immense block was supported upon a timber platform of great strength, beneath which were placed a series of axles with grooved ends that worked or ran upon balls of copper 6 inches in diameter. The axles of the carriage were moved

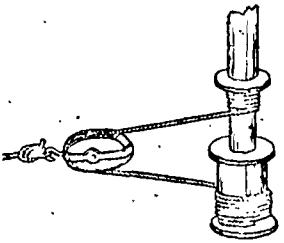


Fig. 1498.

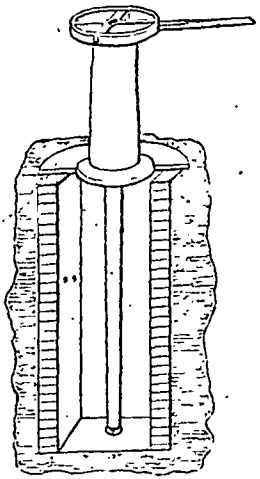


Fig. 1499.

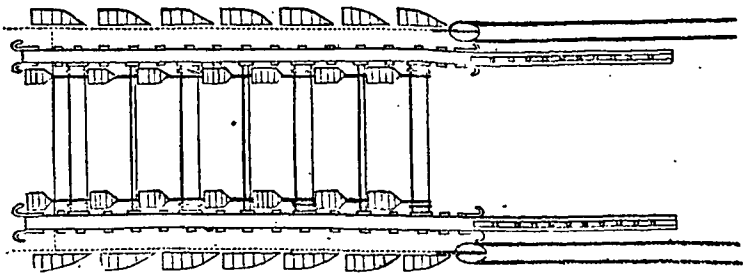


Fig. 1500. PLAN OF CARBURY'S MACHINE.

by the revolution of the balls, on a bed prepared to receive them, which was movable to the fore part of the frame as the carriage progressed, forming a sort of continued railway; one of these pieces of timber is shown under the side elevation.

The end or front of the stone mass was cut into steps, on the top of which the director of the operation took his station; from whence he could make the various signals necessary for the progress of the machine.

The capstans, firmly fixed, were worked by levers and pulleys; and as one set of workmen became fatigued with turning them, they retired to mats attached by other ropes to the flanks of the carriage and were drawn along, steadying the block at the same time, whilst others who had previously rested took their places. This operation rivals that described by Herodotus of the transport of the enormous rock, 240 feet in circumference, which was brought from the quarry in the Isle of Philoe near the cataracts, for the shrine of the goddess Latona, thousands of labourers being employed three years in taking it to its place of

destination; he also informs us that the temple, consisting of one solid stone, was a cube, the length of whose side was 40 cubits

We can scarcely imagine it possible to move so vast a block, the original weight of which would be upwards of 100,000 tons; but supposing that four-fifths were cut away previously to removal, to produce the character of an Egyptian temple, there would still remain 25,000 tons to transport by the aid of levers, capstans, pulleys, and inclined planes. The interposition of rollers or balls in the above arrangement of Count Carbury bears some resemblance to the application of fluids: supposing surfaces to be flat and parallel, a roller will move between them without much friction; but it will have to overcome the resistance occasioned by the depression which it produces in the substance on which it moves, and which is greater or less according to its softness or want of elasticity: if perfectly elastic, the depression would be productive of little resistance, because the tendency to rise behind the roller would be equivalent to the force opposing its progress, the actual resistance arising from a want of elasticity in the materials made use of. In this case, by laying down rails in front of the mass to be moved, upon which the balls could turn, the objection usually made to their introduction was obviated; but had they been placed between two cylinders, one convex and the other concave, much of the friction would have been avoided; it is always materially diminished by lessening the velocity of the parts which slide on each other, as is proved by reducing the diameter of an axis on which a wheel turns.

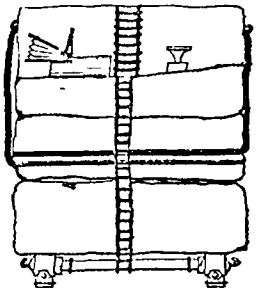


Fig. 1501. END VIEW,

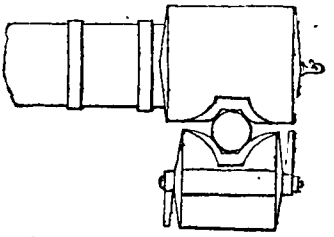
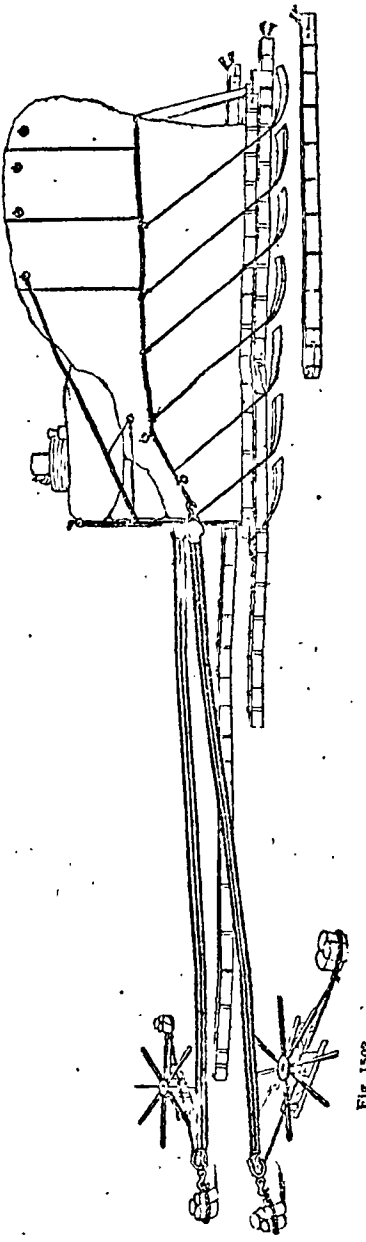


Fig. 1502. THE BED, BALLS, AND AXLES.



MOVING ROCK AT ST. PETERSBURGH: SIDE VIE

Fig. 1503.

Combinations of wheels are generally used where heavy weights are to be moved, or when, by the application of great power, a higher velocity is required: for the first the power must be applied to the circumference of the first wheel, and its pinion must transmit the motion to the teeth of the second wheel, and so on, in order that the weight may be

raised by the axle of the last wheel: in the second case the power must be applied to the first pinion.

The Crab employed for raising weights has a winch and barrel worked by a wheel and pinion; the whole is fixed in a strong frame either of timber or iron, and may be moved into any situation where it is required. A double handle enables two men to lift considerable loads; and the machine is furnished with a brake, so that it may be stopped at any time, whether in raising or lowering a weight. Two crabs worked by six men each, at the London Docks, raised a weight of 728,000 lbs. to a height of 16 feet in 8 hours, equalling 2012 lbs. raised 1 foot high per minute by one man.

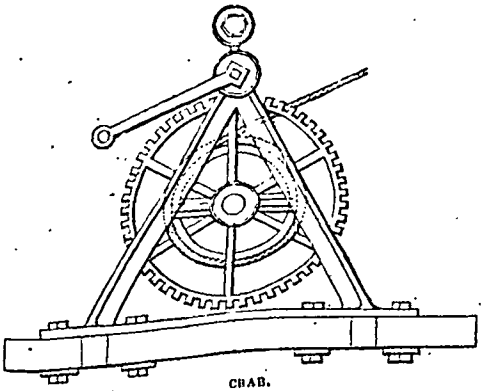


Fig. 1504. CRAB.

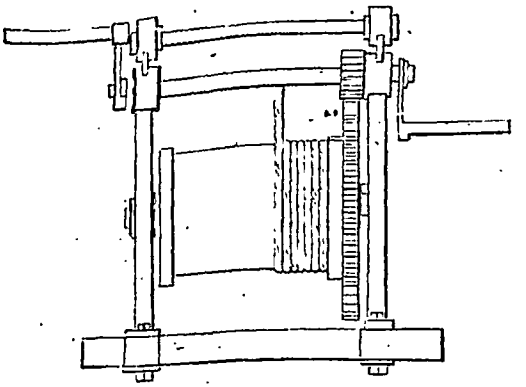


Fig. 1505. CRAB.

The Gin usually accompanies the crab in raising large stones; it is composed of three long stout legs, 12 or 14 feet in length and 6 inches in diameter, meeting together at the top, and so placed that two can be fixed at a certain distance from each other by means of two iron bars placed horizontally, one being 12 inches and the other 7 inches long: a roller upon pivots turns between two cheeks attached to two of the poles, 7 or 8 inches in diameter and 6 feet in length, 20 inches of which are left square at each end, and holes are made in each to receive handspikes, by which the roller is turned; the middle is cylindrical, to wind up the rope. The transverse iron bars are fixed at one end to one of the poles by a bolt, and at the other to the other pole with a bolt and key, which enables the gin to be separated and removed. Each cheek is fastened to the pole by two iron bands and two iron bolts, between which the cylinder revolves: the poles are usually hooped round at each end, and to the upper are straps through which an iron bolt passes to keep them together, and hold up the block through which the rope or chain runs to the crab or windlass. The block contains two pulleys, and before the machine is mounted for use, it is laid down flat on the ground, the lower end of the single pole being turned over, for the purpose of fastening the upper block, and when the rope is turned round both the machine is raised.

The Jack or Hand-jack is a portable mechanical power for elevating the end of a block of stone or piece of timber, to allow of rollers or blocks being placed underneath; or to lift up girders, brestsummers, or to hold up a wall that requires underpinning, and is one of the most useful mechanical contrivances in the hands of the builder. The power of the common hand-jack is obtained by a rack and pinion, placed in a block of wood about 30 inches long, 10 inches broad, and 6 inches wide: the rack has a double claw at its upper end, and a small pinion which engages in the teeth; the axis of the pinion is supported in two iron plates bolted to each side of the block.

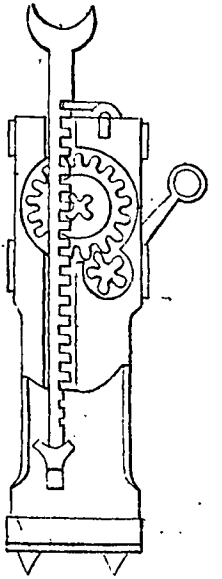


Fig. 1506.

80280.

and one axis passes through the side plate, to which is attached the winch or handle; this, turning round, elevates the rack, and with it the claw which is applied to the load to be raised: that the weight should not have the power of running the pinion back, the handle is secured by a hook fastened to the outside of the block.

There are several modifications of the jack; one of the most powerful is that in which the winch does not immediately act upon the rack, but first on a small pinion, then a large toothed-wheel, which carries a pinion that elevates the load: supposing R to be the length of the winch, R′ the radius of the wheel, r that of the first pinion, and r' that of the second, then

$$P : W' :: r : R$$
$$W' : W :: r' : R'$$
$$P : W :: rr' : R R' :$$

whence $$P = \frac{r \cdot r'}{R \cdot R'} \cdot W$$

Let $r = r' = 1$ inch, $R = 10$ inches, and $R' = 5$ inches; then $P = \frac{W}{50}$, or 1 lb. power would be a counterpoise to 50 pounds; and by exerting a force equal to an hundred weight, or $112 \times 50 = 5600$ lbs. might be raised.

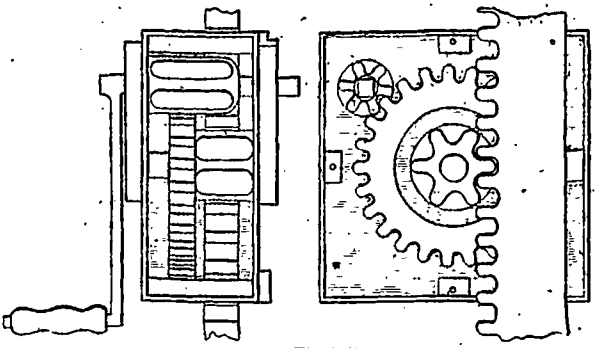


Fig. 1507.

A small power may thus elevate a considerable weight, but in so doing, the total expenditure, in raising the weight through any height, is never less than that which would be expended if the power were immediately applied to the weight, without the intervention of any machine: this arises from the universal property of machines, by which the velocity of the weight is always less that that of the power, in exactly the same proportion as it is less than the weight, so that when a certain power is applied to raise a weight, the rate at which it mounts is always slow, and in the same proportion as the weight is great; no machine, therefore, can be said to have the property of totally diminishing the expenditure of power necessary to raise the weight or to overcome its resistance; all that a machine can effect is to enable the power to be expended at a slow rate, and more beneficially in its duration, than if applied at once to the weight or its resistance; this common property refers to all the mechanical powers, as the lever, the pulley, the inclined plane, screw, &c. &c.

The Screw is applied both to raise weights and press bodies into a more compact state; and sometimes to set in motion the sun and planet wheels; the worm of the screw working into the teeth of that wheel which drives the gear, and by its revolution compelling the wheel to move on its axis; it is also preferred to the jack wherever a delicate movement is required.

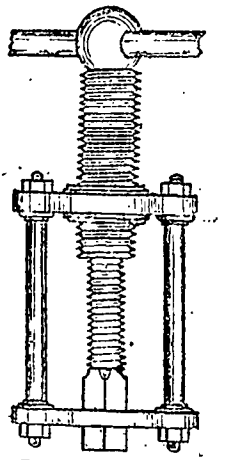


Fig. 1508.

The working of the screw may be understood from the observations made upon the inclined plane, and by considering that the weights rest on the inclined face of the thread, whilst the power acts on the surface of the cylinder parallel to the base of the screw: equilibrium is obtained when the power, is to the resistance, as the distance between the two threads of the screw, is to the circumference described by the point to which the power is applied.

$$P : W : h : 2rw,$$
$$\text{and } P = \frac{h}{2wr} W :$$

W being the weight or resistance to be overcome, h the height or distance between the threads, and r the radius of the screw. The space described by the power, is to

that described by the resistance, as the circumference of the screw, is to the distance between two of the threads: in some of its applications, these powers are multiplied by one screw working within another; the larger, turning round within a fixed nut, has a progressive motion, whilst the smaller one is made to work within it.

For presses the application of the screw is very simple, although the friction which accompanies it materially affects its power; but it is of service in maintaining the press in the position in which the force has brought it; it is always turned by a lever, without which the friction would render it useless. The double screw may be used with considerable advantage wherever a small extent of motion is required. The screw of the printing press having to descend with great momentum, it is made more open; and in all such cases the handle must be loaded.

For raising weights, the screw has been substituted for the rack and pinion of the common jack, and for many purposes it is far better adapted; the mason requires the use of such a machine for the elevating the massive stones he has to work upon, and for ordinary purposes it is much more convenient than the lever.

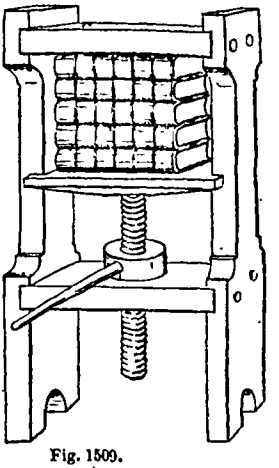


Fig. 1509.

Screw Jack.—The block of wood has a hole bored through nearly its entire length for the purpose of allowing the screw to move up and down without touching: at the top of the block is firmly fixed a nut, through which the screw passes when turned round. The claw fitted at the top and bottom of the screw has a round collar, which allows the screw to revolve without turning it: at the bottom of the block are four points to prevent its slipping when used. The motion is given to the screw by a worm wheel fitted upon the square, the teeth of which are engaged by a worm on the axis of the winch; when this is turned round, it causes the wheel to revolve by the action of the worm in its teeth, and as the wheel is attached to the square part of the screw, it is compelled to turn with it, permitting the screw to move up and down at the same time.

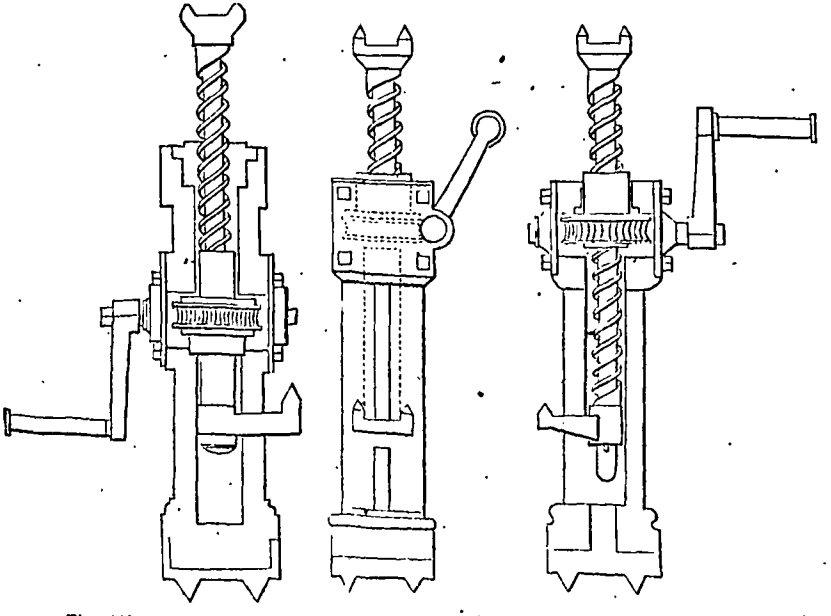


Fig. 1510. SCREW JACK. Fig. 1511. SCREW JACK.

In another description of screw jack, not having so much friction, the screw does not turn round, but only rises and falls; this is effected by the worm wheel being placed near the top of the block, which has a nut cut in its centre, through which the screw passes, and the nut is turned round instead of the screw. The axis of the worm is supported by similar iron plates to that already described, and is also turned by a winch.

The Crane is generally employed for raising or lowering heavy weights and large bodies, for removing them from one situation to another, loading and unloading waggons and ships, and for hoisting goods from the quay to the different warehouse floors: it consists ordinarily of an upright post turning upon pivots; the gib or arm which extends from the upper part is now generally made of iron, or supported by a bracket of the same material.

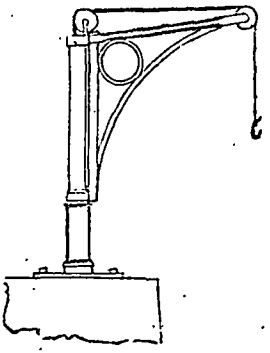


Fig. 1512.

The wheels accompanying it are usually set in motion by turning a winch, a fly wheel being applied to the axis to equalise the motion, as well as to prevent the rapid descent of the load, should any accident occur. The powers of the crane are adapted to its intended use, and the weights to be raised: some have a variety of movements introduced, with a train of several wheels, each turned by a pinion smaller than itself. If the barrel or drum on which the rope winds be 12 inches in diameter, with a cog-wheel having 96 teeth attached to the end of it, it may be turned by a pinion of 12 leaves. On the same axis may be placed a wheel of 32 teeth, moved by a pinion of 8 situated on a third axis, which carries the fly wheel: a winch of a foot radius applied to the gudgeon of the drum or barrel, doubles the power of the labourer, as the circle it describes is double that of the barrel on which the rope winds. If the winch is fixed on the axis which carries the pinion of 12 and wheel of 32, it will have a power 16 times greater, and if attached to a pinion of 8, 64 times. The fly wheel being fixed upon the axis on which the pinion of eight is attached, all danger from accidents is in a great degree prevented, and is much more effective than the brake and ratchet-wheel. The spindles of all the wheels slide or push endwise, so that they may be combined or disengaged at pleasure.

The statical moments of the forces are inversely as the product of the radii of the axis, to the product of the radii of the wheels in which they work; and as the number of teeth which the wheels and leaves that the pinions carry must be as the peripheries of the wheels and axles, their statical moments are also inversely as the product of the leaves of all the pinions, to the product of the teeth of all the wheels.

At Ramsgate harbour a crane was made use of, designed by Mr. Peter Kier, by which four men were enabled to hoist as many tons: the whole was mounted upon a frame of cast-iron, 9 feet 7 inches square, weighing 2 tons; this was supported on four cast-iron wheels, one pair of which on a common axle moved round on a centre, fixed to one side of the frame: an arm projected from the axle to the opposite side beneath the framework, where, by means of a rack or segment of a wheel fixed to it, a pinion moved by a winch twisted the wheels round upon their centre, and allowed the whole crane to be moved in any direction required.

The shaft of cast-iron weighing 23 cwt. was placed over the centre of the iron frame, and supported by oak braces, stepped into boxes, cast in the angles of the frame, thus forming a strong perpendicular shaft, round which axis the whole crane traversed: a steel pivot or gudgeon at the top of the shaft supported the weight of the entire framing and wheel-work. The former consisted of a long beam, bearing the pulley at one extremity, and the wheel-work or machinery at the other; the whole was further strengthened by braces and uprights, to which the platform was attached, on which the workmen stood. This crane has since been greatly improved, by being made to balance itself perfectly when hoisting a load, and to facilitate its turning on its pivots, additional machinery is sometimes applied.

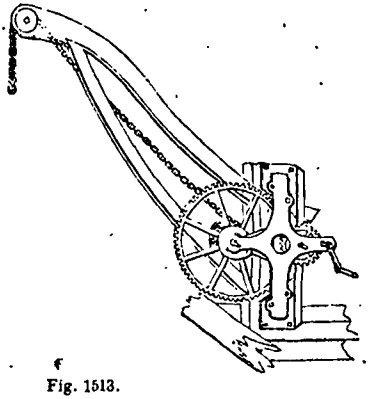


Fig. 1513.

At the West India Docks six men working a crane raised 224,000 lbs. weight 15 feet high in 8 hours, which is equal to 1166·6 raised a foot high per minute by one man. The friction of this crane was equal on an average to one-twelfth of the absolute weight.

Wharf Cranes. — Where cranes cannot conveniently be held by an upright post, they may be supported by a piece of framing, as in this example. On the wharf is laid a sill 35 feet in length, and 12 inches square, under which at right angles is another piece of the

same scantling, 30 feet in length; into the ends of this are framed two inclined braces, 39 feet in length and 7 inches square, secured by three iron bolts to the head of the inclined timber, 39 feet in length, as shown to the left of the figure. The post of the crane,

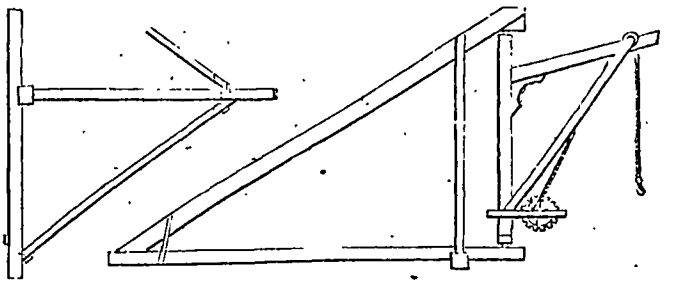


Fig. 1514. WHARF CRANE.

12 inches square, works on a gudgeon, both at top and bottom; the inclined piece holding a metal box for the foremen, and the sill, that for the latter to work in. The gib, 12 feet in length and 12 inches square, is braced by another piece, 6 inches by 4. This kind of crane with a wheel 3 feet 4 inches diameter, and pinion 6 inches, is much used in Scotland.

Another variety of wharf crane is shown in the accompanying figure, where the framing is formed above, not lying immediately on the ground. The plan of the top is triangular, each side being 29 feet in length, and 12 inches square, secured at the angles by cast-iron

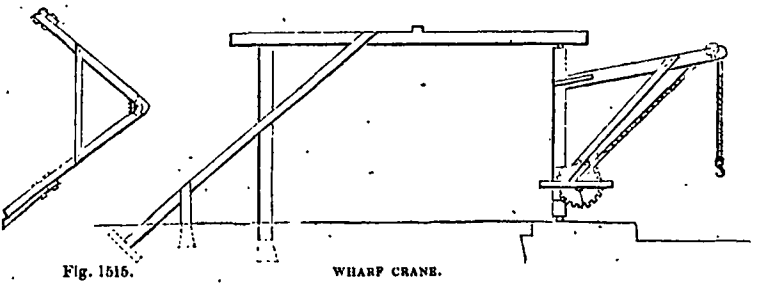


Fig. 1515. WHARF CRANE.

boxes, and cross-braced. The upright post, 12 inches square, works top and bottom on a gudgeon, and the gib, 14 feet in length, and 12 inches square, is braced to it by a piece 6 inches square. By this crane ordinary weights are landed at the wharfs of many of the canals.

When the wheel and axle are applied to raise a weight, the velocity with which the power moves is as many times greater than that with which the weight rises, as the weight itself is greater than the power; hence it is that in the elevation of the weight a quantity of power is expended equal to that which is required to elevate the weight, if the power were immediately applied to it without using any machine. When in one revolution of the machine the length of rope uncoiled from the wheel is equal to the circumference of the wheel, it is through that space the power must move; and at the same time we shall find that the length of rope coiled upon the axle is equal to the circumference of the axle, and through this space the weight must be raised; the spaces, therefore, through which the power and weight move in the same time are in the proportion of the wheel and axle, and these cir-

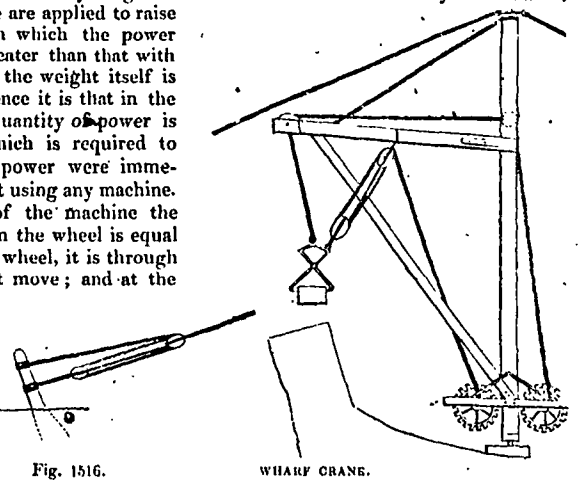


Fig. 1516. WHARF CRANE.

cumferences are in the same proportion as their diameters; therefore the velocity of the power will bear to the velocity of the weight the same proportion as the diameter of the wheel bears to the diameter of the axle, or as the weight is to the power.

When the upright post is secured by chains or ropes, the triangular timber frame is dispensed with, which is sometimes necessary in building a quay wall. By means of blocks the whole of such an arrangement can be lightened at pleasure, and made perfectly secure.

Double Crane, fixed on a wharf or pier-head, is so framed and braced that it balances exactly when turning on a pivot at the bottom. Such a crane was used at the constructions on the Rochdale Canal: the distance between the ends of the gibs was 30 feet; they were held together by a bar of iron, 1¼ inches square: their scantling was 8 inches by 7½ inches; the length of each of the cross braces was 27 feet 6 inches, and their scantling 7 inches by 6. The upright post was a foot in diameter, and the segmental piece which swung round upon its head, 12 inches by 9. The wheels were 3 feet 4 inches in diameter, the pinion 6 inches, and the rollers 12 inches, the latter being 2 feet 9 inches in length.

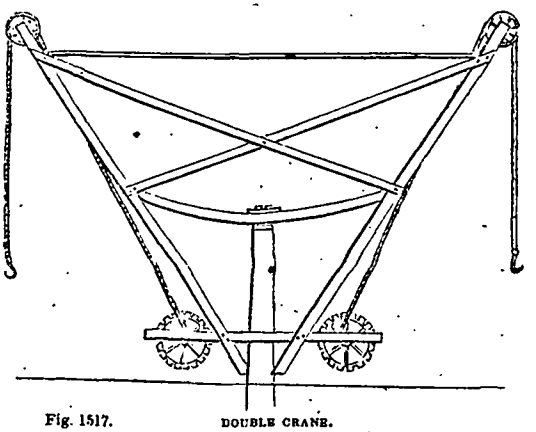


Fig. 1517. DOUBLE CRANE.

Iron Pit Crane composed of a cast-iron frame shaft and gib, has usually three different powers, each power having a double purchase. The height of the shaft is 20 feet, 11 of which is below the surface of the ground; it rests on a gudgeon about 6 inches in diameter, and turns in a brass box. At the surface of the ground two plates are fixed to the shaft, 4½ inches apart, between which are five rollers; when the crane is turned, these move round the inside of a cast-iron circle. The gib and proportions of a crane to carry eight tons is 21 feet in length, and the diameter of the winch is 3 feet; that of the pinion taken at the pitch line 5¼ inches with ten leaves: the wheel in which it works is 3 feet 4½ inches in diameter, with eighty-four teeth: the second pinion is 7¾ inches in diameter, with fifteen leaves, and the wheel 3 feet 1¾ nches in diameter, with eighty teeth: the third pinion is 1 foot 3¾ inches in diameter, with thirty-two leaves, and the wheels 2 feet 5½ inches in diameter, with sixty-two teeth. The pinion common to all the powers is 5¾ inches in diameter with eleven leaves, and the wheel 4 feet and ¾ of an inch in diameter, with 100 teeth. The chain barrel is 16 inches in diameter, and the friction rollers for the chain 9 inches.

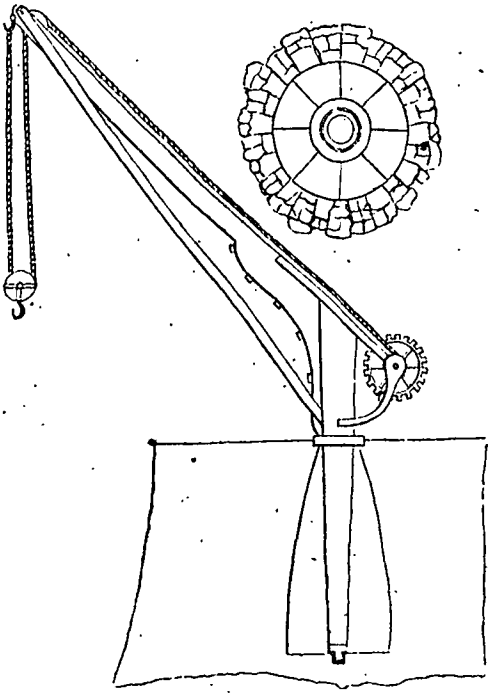


Fig. 1518. WHARF CRANE.

The Corvus or Raven of the ancients, according to Perrault, corresponded to our crane; each comprised a strong arbor, or upright timber, firmly fixed in the ground, and sustained by

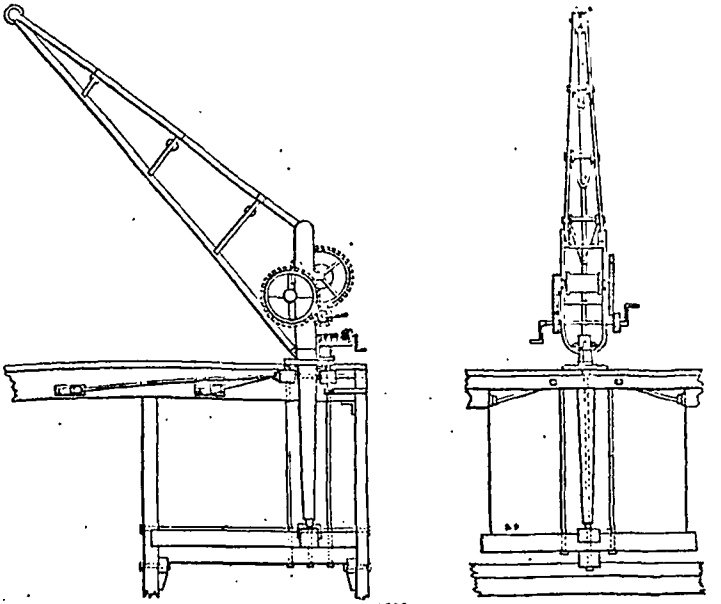


Fig. 1519.

a number of arms, according to the strength required: when the entire crane turned with the load, it was originally called rat-tail, and when only a portion moved, it was termed the gibbet crane.

Double Crane, used for the construction of breakwaters, is mounted upon a frame, and by means of rollers, and a working gear, can be readily moved forwards or backwards: when advanced to the edge of the work one gib can be employed to lay a stone, whilst the other lifts one from the carriage, which is moved along a railway laid down for the purpose. The gib has a sliding carriage for laying the stones either close to the shaft, or as far out as it will reach: it is worked by a sheeve and rope passing over the point of the gib, and down by the side of the spindle.

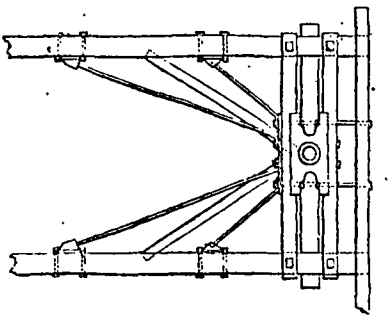


Fig. 1520.

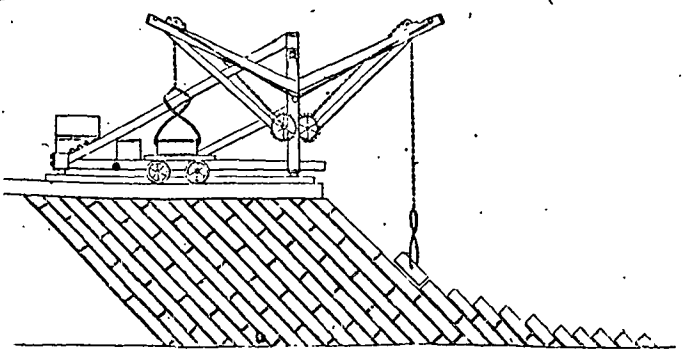


Fig. 1521. ABERDEEN: DOUBLE CRANE.

A gib crane with a shaft 40 feet in height and 12 inches square, turning upon a gudgeon at the bottom, is frequently used in building lock walls, &c. At the top is a similar

gudgeon, on which a plate with four arms and a hole in the centre is dropped: to each of these arms is fixed a guy rope, which is carried to such a distance from the shaft, that when the crane turns round, the gib may keep clear of it.

The lower end is thus connected with a pair of pulley blocks, previously fastened to a pile driven in the ground, and then drawn tight and secured. The gib, usually 26 feet long and 10 inches square, is fixed a little higher than the middle of the shaft; it is supported by a brace from below, and is suspended from above by a wrought-iron bolt, and worked by a common wheel and pinion.

Fig. 1522.

The pincers or forceps, for holding the stone elevated by the crane, is made of iron, and the pivots or rivets are of considerable strength: when the rope is pulled, the points which attach to the stone are drawn or pressed together in such a manner, that the heavier the weight the firmer it holds.

The movable crane for lifting the timbers employed in the construction of the cones for the breakwater at Cherbourgh was very simple, and was brought immediately over its work. The several pieces were pulled up, and lifted into their respective situations by means of a pulley.

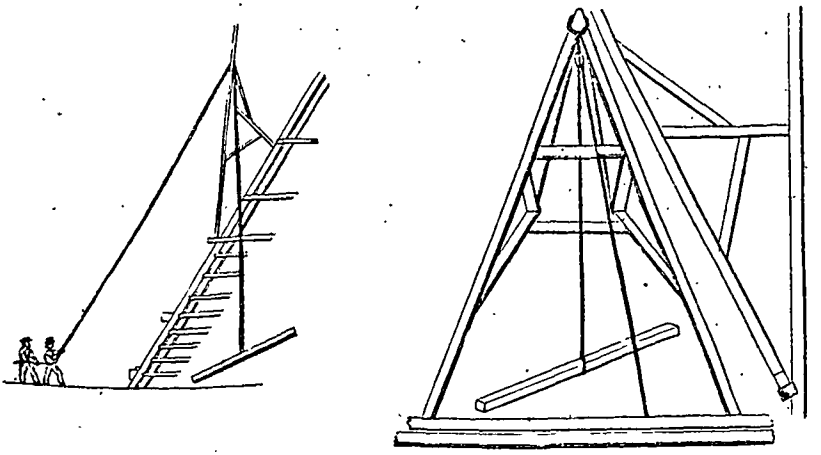


Fig. 1523. MOVABLE CRANE FOR BUILDING CONES AT CHERBOURGH.

Where the wheel and axle is used in cranes, the action of the power is liable to occasional intermission, in which case a ratchet wheel is provided, which permits the wheel to turn only in one direction, the catch which falls between the teeth of a fixed wheel preventing its motion in the other direction. The power of the wheel and axle being expressed by the number of times the diameter of the axle is contained in that of the wheel, there are but two methods by which that power can be augmented; viz. by increasing the diameter of the axle, or lessening that of the wheel. Where great power is required, each of these methods presents some difficulty as well as inconvenience; for if the diameter of the wheel is enlarged, the power will work through an unmanageable space; and if the other method is adopted, and the thickness of the axle is much reduced, its strength will become insufficient for the purpose of supporting the weight: to combine, therefore, strength with moderate dimensions, is sometimes accomplished by the methods we have already described of giving different thicknesses to different parts of the axle, carrying the rope which is coiled to the thinner part through a wheel attached to the weight, and coiling it in the opposite direction on the thicker part. In Eckart's power capstan, fig. 1494., the weight is equally suspended by two parts of the rope; therefore each part is stretched by a force equal to half the weight; consequently the power multiplied by the radius of the wheel, is equal to half the weight multiplied by the difference of the radii of the thicker and thinner parts of the axle; or, the power multiplied by the diameter of the wheel, is equal to the weight multiplied by half the difference of the diameters of the thinner and thicker parts of the axle: such a wheel and axle is equivalent to an ordinary one, in which the wheel has the same diameter, and whose axle has a diameter equal to half the difference of the diameters of the thicker and thinner parts. The power of such a contrivance depends upon the proportion the diameter of the wheel bears to half the difference of these diameters; therefore this power, when the diameter of the wheel is given, does not depend on the smallness of the axle, but on the smallness of the difference of the thinner and thicker parts of it.

The crane used by Perronet at the construction of the bridge at Neuilly was also exceedingly simple: it was of timber, and worked by two wheels, one man at each wheel being

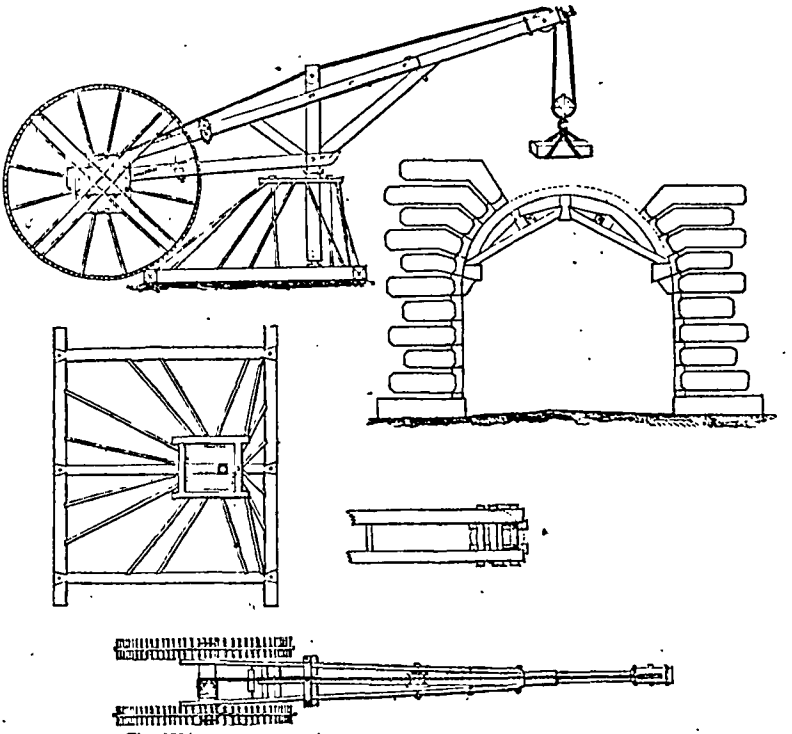


Fig. 1524. PERRONET'S CRANE USED AT NEUILLY.

sufficient to hoist the various stones used in laying the courses and placing the voussoirs over the arches.

By means of two wheels mounted on a plane, the stones were lifted from the wheel

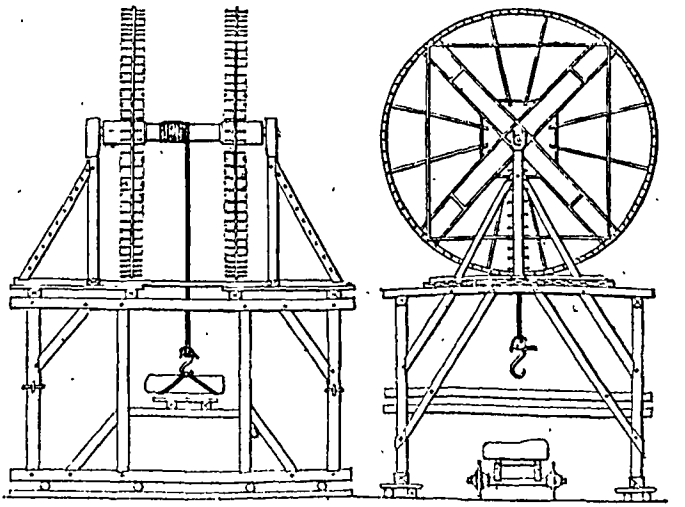


Fig. 1525. PERRONET'S CRANE USED AT NEUILLY.

carriages, and placed upon the platforms, whence they were again moved to their several places of destination.

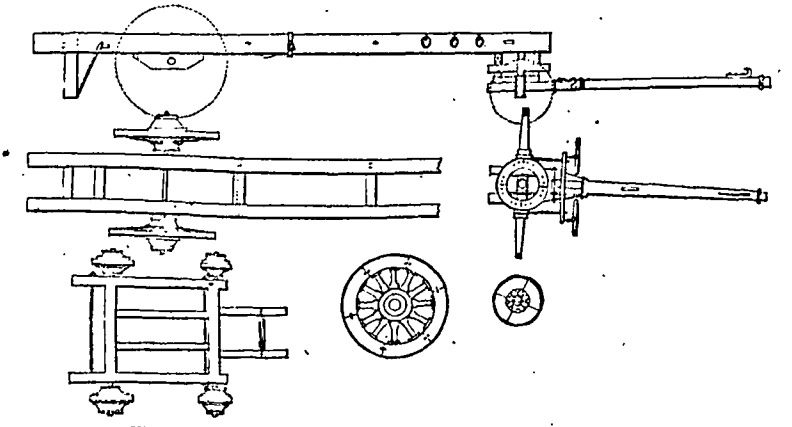


Fig. 1526. PERRONET'S CRANES USED AT NEUILLY BRIDGE.

In wheel cranes we have an example in which the body receives an impulse in a direction perpendicular to the axis, and where a uniform rotatory motion is produced, the velocity of which depends on the force of the impulse, the distance of the direction of the impulse from the axis, and the manner in which the mass of the body is distributed round the axis: we must also consider, that the whole force of the impulse is distributed amongst the various parts of the mass, and is transmitted to them from the point where the impulse is applied, in consequence of the cohesion of the parts, and the impossibility of one part yielding to a force, without carrying all the other parts with it.

Another crane used by Perronet at the bridge of Orleans, with a very simple framing, was also worked by a wheel, as is still the custom throughout France: at all the quarries in the neighbourhood of Paris wheels are made use of to hoist the blocks of stone. This kind of crane requires to be well balanced to be effective, and in this example great attention was paid to this point.

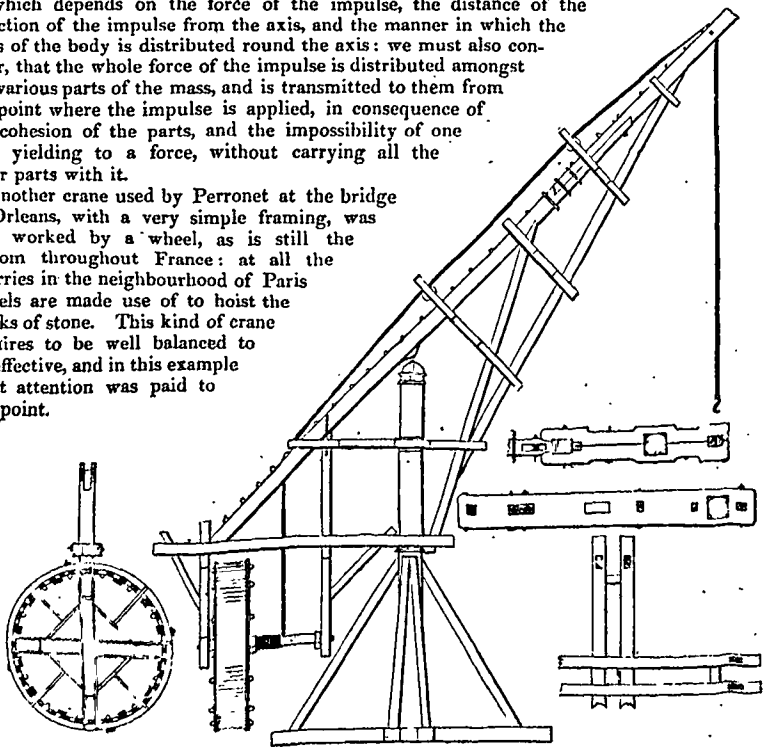


Fig. 1527. PERRONET'S CRANES USED AT ORLEANS BRIDGE.

In some experiments made at the London Docks with a wheel crane worked by six men, a weight of 787,920 pounds was raised 7 feet in 8 hours, equal to 1915 raised one

foot high per minute by one man. At another trial the six men raised a weight of 911,680 pounds 8 feet high in 11 hours, which was equal to 1841 pounds raised a foot high per minute by one man.

The gib of a crane should always revolve wholly round its axis, and be able to deliver the load at any point of the circle described by the axis of the gib: in the crane employed by Perronet at the bridge of Orleans, the whole machinery was made to revolve, which method answers admirably well, if the necessary space can be spared.

The gib apparently worked well in one particular, for as the rope by which the stones were raised passed over the upper gudgeon, and then between two small vertical rollers, when it was turned round, the rope always laid fair to the windlass, while in many other cranes the contrary takes place; so that when the gib is turned on its axis, the rope is so bent that it forms an angle more or less acute, which causes a great increase of friction, and a continual effort to bring the arm of the gib into a parallel position with the inner part of the rope: much inconvenience arises also from attempting to keep the gib in its true position by guy ropes, or other contrivances where the crab or windlass is in a fixed position, and not so attached to the crane as to revolve with it.

Perronet balanced this crane so equally, that when poised upon the post upon which it turned, it worked freely in any direction.

The windlass or barrel on which the rope winds had two wheels fixed on the axis, at some distance apart, which being united with boards formed a large hollow cylinder or drum, and was worked by men walking upwards on the inside. But to this method there are many objections: a wheel 16 or 18 feet diameter does not afford sufficient leverage for men so placed to turn it with much effect, and they are often overpowered by the load, when, if one makes a false step, or slips down, the wheel runs back with accelerated velocity, and throws them against the sides and each other with tremendous violence, often occasioning death.

It is indeed surprising that such cranes should have been used almost universally by the engineers of the last century.

A walking wheel is, however, an advantageous method of employing the strength of a labourer, but the requisite dimensions of such a machine render it sometimes inconvenient, and unless large, it is not sufficiently powerful; if, however, it be worked on the outside instead of the inside, this objection is obviated, but there should always be some means provided to prevent the too rapid descent of the weight of the labourer, should he by any accident be compelled to quit his position, and a catch is usually introduced, which counteracts any retrograde motion, and in some instances a bar is suspended from the axis of the wheel, on which he can support himself with his hands.

Other wheels of this description are made to incline a little from the horizon, and the labourer walks on its flat surface, but these are not preferred, on account of the great loss of power whenever the machine is stopped: when horses or other animals are used to tread a wheel, the path within it should present as little elevation as possible, but their power is always more advantageously employed in a circular mill-walk.

In the construction of piers it is often convenient to have a revolving crane that will permit the stone not only to be lifted out of the lighter, but also passed round to the side or position in which it is intended to be laid; and this can be easily effected by making

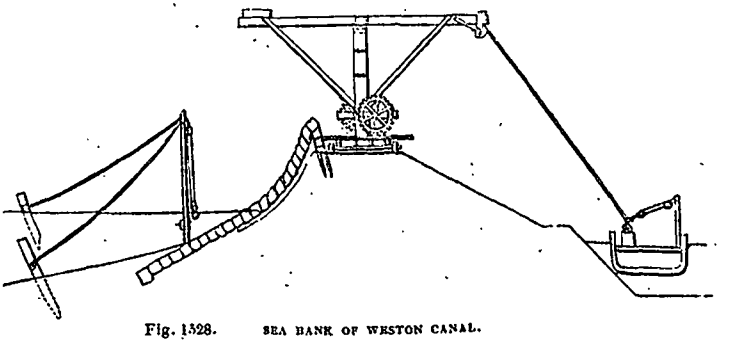


Fig. 1528. SEA BANK OF WESTON CANAL.

the gib or arms sufficiently long, and bracing them equally on each side; when thus balanced properly the whole may be turned on its pivot, with the load suspended at one extremity; and for the construction of sea-walls, such a crane has been found highly useful.

Derrick Crane used at Granton Pier, Edinburgh, was of a very superior kind, and was executed by Mr. Wightman: it consisted of a vertical post, supported by two timber back stays, and a long movable derrick or gib, hinged at the bottom of the post; the top of this gib was held by a chain, which passed from a barrel over a pulley at the top of the post, so that the gib could be raised or lowered. This crane commanded a circle of from ten feet to sixty radius without being moved.

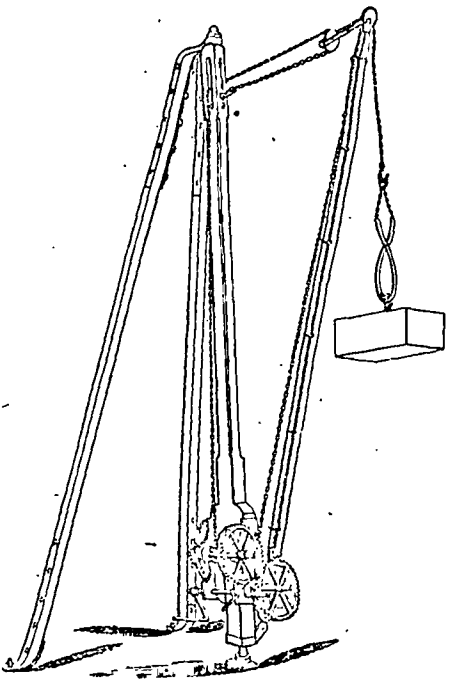


Fig. 1529. DERRICK, GRANTON PIER, EDINBURGH.

A similar machine was used by the ancients, and is thus described by Vitruvius:—"Three pieces of timber are prepared, suitable to the weight to be raised, connected at the top by a pin, but spreading extensively at the feet; these are raised by means of ropes made fast to the top, and when raised are kept steady; to the top is fixed a block, by some called *rechamus*, in which two pulleys turn on axles."—(Vit. cap. ii. lib. 10.)

Tackle used by the East London Waterworks Company in hoisting their Stand Pipe.—A piece of timber 9 inches square was attached to the upper flanch of the pipe, and held in its place below by an iron hoop or girdle. Guy ropes were fastened at the top of this upright, which served also to suspend the snatch blocks through which the fall ropes passed to the crab winches: attached to the iron hoop were two pivots which traversed the lower ends of two timber gibs, connected at top by a cross timber, from the centre of which were suspended the blocks and tackle connected with the large crab. After each joint of pipe had been elevated to its place, the gib frame was drawn up vertically by the tackle from the small crab, and the pipe was lowered to its place; the pins were then passed through its flanches. This operation was continued for each successive length of pipe, until the whole had reached a height of upwards of 130 feet.

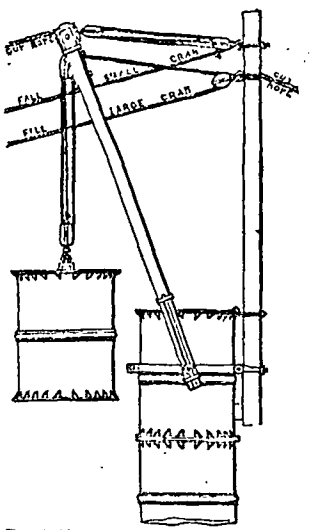


Fig. 1530. EAST LONDON WATERWORKS.

The architects and engineers of the middle ages were celebrated for moving and lifting great weights, and probably the inscription at Pisa Cathedral, which informs us that Buschettum in the eleventh century raised the granite columns, each weighing upwards of 16 tons, by a machine so simple that children could work it, refer to similar contrivances as those now under our consideration: the inscription is curious, as it exhibits the admiration which this engineer called forth by his ingenuity.

QD VIX MILLE BOU POSSENT JUGA JUNTA MOVE
ET QUOD VIX POTUIT P MARE FERRE RATIS
BUSKETI NISU QD ERAT MIRABILE VISU
DENA PVELLARE TVRBA LEVABIT ONUS.

Devonport Column is built of granite from Holman's Hill quarry, and is in height 101 feet 4 inches above the surface of the rock upon which it stands: the shaft is 11 feet in diameter, and its height to the top of the capital 65 feet 4 inches; the abacus is formed of four stones, each weighing between three and four tons. Mr. John Fulston raised the stones

which compose this column without the use of scaffolding, by means of a series of tall spars joined together, like the mast of a ship; the lowest being fixed firmly in the ground, and braced by diagonal pieces, as well as lashed and strutted to the lower part of the shaft. A gaff, with a jaw at the lower end, was then slung in the throat by a strong rope or chain, so as to work round the upper spar in the jaw prepared for it; from the ends of this gaff, blocks and a fall were suspended, which, by raising or depressing the point of the gaff, commanded every portion of the work. The stones were raised by means of crabs turned by winches, and the whole work was terminated in a short time.

Obelisk on the Whitaw Eskdale, erected to the memory of Sir John Malcolm, is in height 100 feet above the foundation; it is built with a hollow space in the middle, with whole courses occasionally passing through; in these a large circular hole was left, and the crane was raised after the completion of each course. It was thus formed:—In the lower hole was inserted a pole 10 inches in diameter, and 40 feet in length; the next hole above served as a stay, whilst the upper one supported the whole weight, a collar of hard wood being firmly fixed around the pole. Beneath this collar were introduced 17 metal balls about 3½ inches in diameter, which running in grooves prepared for them enabled the pole easily to turn round. At the top of the pole, and placed crossways, was mortised a beam 12 inches square, and 12 feet in length, strengthened by diagonal iron bars and straps.

The stones were raised by a crab winch, the rope passing over a pulley at each end of the horizontal beam, and moved to their situation by a traversing carriage, which worked on the beam by means of a small crab and pulleys.

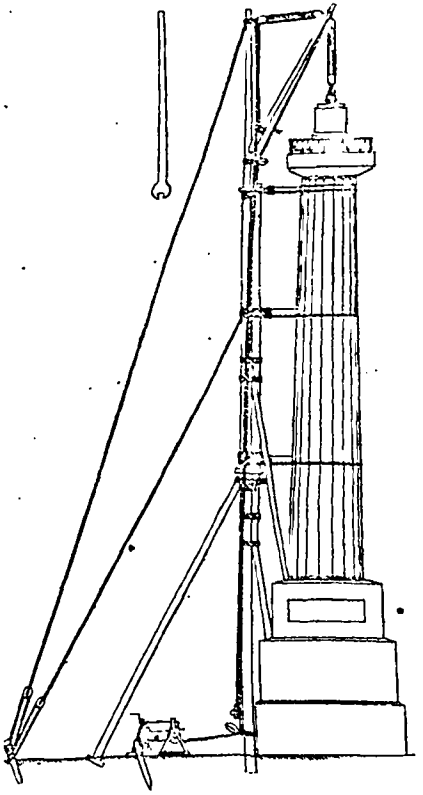


Fig. 1531. DEVONPORT DERRICK.

We cannot perhaps better illustrate our present subject than by giving the account of the manner in which the obelisk in front of St. Peter's at Rome was raised by the celebrated Domenico Fontana; its weight was estimated by that architect as equal to 993,537 pounds; the height is 180 palms, but without the apex 77·2 English feet; the transverse section at the middle contains an area of 7·6 superficial feet; the solid content may, therefore, be taken at upwards of 166 cubic yards, weighing about 332 tons; if to this be added 4 tons for the weight of the apex, the whole weight of the obelisk raised is upwards of 336 tons. The length of each of the sides at bottom is 12½ palms, and at top 8½ palms, the palm being equal to 8·7 English inches: 46 cranes, 600 men, and 140 horses were employed in removing it, and the timber, ropes, and iron made use of cost 20,000 crowns. The operations for removing it, which were conducted with the greatest skill, were as follows:—

A scaffold, called a castellum or shears, was first constructed, 7 feet higher than the top of the obelisk when mounted on the pedestal. The eight principal timbers, four on each side, were 89 feet in height from the foundation; they were each built of oak and walnut, four beams in thickness, and banded at every 9 feet with strong iron hoops, and bolted together in several parts. The whole was so arranged that it could be easily put up or taken down, to suit the several positions in which the obelisk might be placed: wherever this castellum was to be used, 4 holes 3 feet square were prepared in a platform of travertine stone, into which the four posts were dropped and secured.

The obelisk was cased over with double mats to protect it from injury; was then covered with two-inch plank, and longitudinal iron bars, 4 inches in breadth, were attached to it, three on each of the four sides; these, connected together by nine iron hoops, served to attach the tackle; this coating of mat, wood, and iron was estimated to weigh as much as one-twelfth of the obelisk. Thus entirely covered, the obelisk was lifted from the pedestal

on which it stood by means of capstans and blocks attached to the iron hoops, and the blocks hanging to the cross beams of the shears; after it was lifted up two feet perpendicularly, a platform of timber was introduced beneath it, which rested on wooden rollers, 9 inches in diameter, their ends being secured by iron hoops. The ropes of the blocks attached to the four lower angles of the obelisk being drawn, the platform which supported

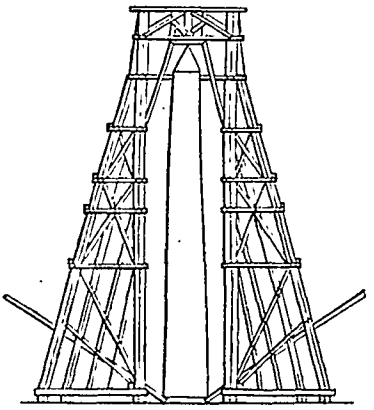


Fig. 1532.

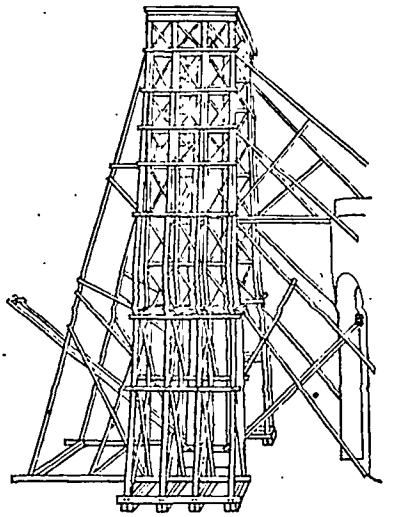


Fig. 1533.

the weight moved on the rollers, and the ropes of the blocks attached to the upper part of the obelisk being slackened, the obelisk gradually descended, and was laid horizontally on the platform prepared to receive it: during its descent it was found necessary to support it in the middle by two shores, made movable on an axis attached to its centre, and which prevented any great strain on the tackle.

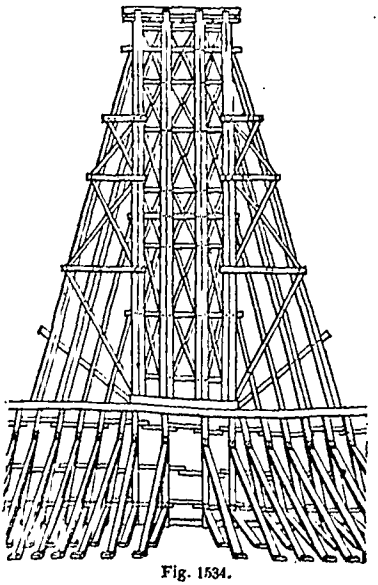


Fig. 1534.

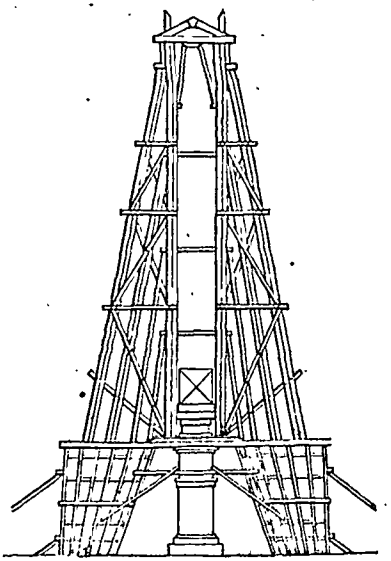


Fig. 1535.

The inclined plane along which it was moved to its destination was formed of a mound of earth strengthened with timbers, and extended from the Circus of Caligula, afterwards

called that of Nero, to the position where the obelisk now stands; its former site is still marked by a stone in the passage leading from sacristy to the choir of St. Peter's. After the obelisk had been moved along this plane upon wooden rollers, the forty-six capstans placed round the mound of earth were prepared for their work of raising: they were fixed in the ground on each side, and each had four arms or handspikes; the first and third arms were worked by a horse, and the other two each by from six to ten men: four of the

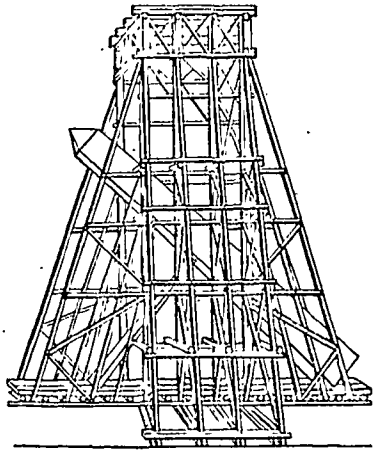


Fig. 1536.

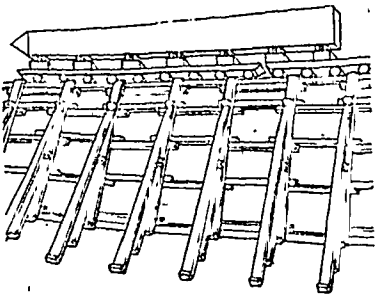


Fig. 1537.

capstans acting upon as many blocks were used for drawing the foot of the obelisk forward, one block to each angle; the other capstans were employed to raise the obelisk into a vertical position. The whole operation is amply described in a work compiled by Fontana, and in which are engravings of the entire machinery.

The foundations prepared to receive this enormous weight were carefully executed: an excavation 43 feet square, and to the depth of 24 feet, was made, and the bottom being found a clay, it was piled entirely over with oak and chestnut, with piles 18 feet in length and 9 inches in diameter, the bark being previously removed from them: upon these was laid a bed of concrete, composed of basalt broken into small fragments, and mortar composed of lime and puzzolana. The total cost of the entire removal was about 9000*l.*

This obelisk, which now reposes on four pieces of metal, firmly run with lead into the pedestal, is one of those which Herodotus mentions as having been erected by Phero, son of Sesostris, when he recovered from his blindness, and which were in height 100 cubits, and 8 wide. Pliny also mentions it: "ejusdem remanet et alius centum cubitorum, quem post cæcitatem visu reddito ex oraculo Soli sacravit."

Caligula transported it to Rome, and dedicated it to Augustus (Ammian. Marcell. lib. xvii.). When Constantine removed an obelisk from Egypt, after floating it on a raft down the Nile, and landing it at Alexandria, he put it on board another raft or ship provided with 300 rowers: when it reached the Tiber, it was landed 3 miles from Rome, and placed on rollers (cuniculis, or chamulcis impositum); then moved slowly to its destination through the Porta Ostiensis: lofty beams, and a forest of machines or capstans were then made use of; the latter, worked by many thousand men, lifted it bodily, and placed it erect upon its pedestal.

The various machines for raising weights mentioned by Vitruvius were made of timber, as were those called *Scansoria*, applied to the walls of a besieged town for the purpose of scaling: these were so contrived that, like a scaffold, they could be quickly put together. The Tractoria were machines employed for raising those heavy masses with which the Romans constructed their temples and public buildings; the same author also mentions the Rotæ, Rhedæ, Cissiæ, Torni, &c., as in common use in his day; he also refers to the *Charchesium*, which is supposed to have been an upright timber, with another lying horizontally across the top, and movable upon a hinge upward and downward, as well as having a horizontal motion around, by which stones could not only be raised from the ground, but conveyed to their intended situation. The tympanum, or hollow cylindrical wheel, are also alluded to by Vitruvius, but he does not inform us how the men who turned it were disposed; and we know, too, that the ancients made use of powerful levers, wheels, and inclined planes for the purpose of moving ponderous masses, or lifting heavy weights: but it cannot be denied that since Fontana constructed his machinery for raising the obelisks at Rome great improvements have been made in this branch of mechanics; considerable attention has been

paid to the arrangement and material employed for the tackle; ropes have yielded in some instances to chains, and levers of great length have been applied, and sometimes a series, turning on sockets at one end, have been used, where it has been necessary to multiply power to any great extent: by the efforts of iron and timber judiciously combined in a well-constructed machine, weights of any amount are now raised with apparent ease and facility.

M. Lebas, an engineer of the Marine in France, was commissioned in 1831 to bring from Luxor in Egypt one of the granite obelisks, and raise it on a pedestal to ornament the city of Paris; it is 75 feet in height, containing about 3000 cube feet, and was estimated to weigh nearly 258 tons.

The obelisk was cased with timber throughout its whole length; underneath its base, at the lower side, was placed a wooden roll or cylinder, C, upon which the whole obelisk turned as upon a hinge during its movement: there were five stays on each side, formed of masts, one of which is shown at D; these were all united at their summit between two others laid at right angles with them, the whole being bound round with ropes. The ten masts rested on a level platform, and their ends being rounded, they worked in a hollow channel

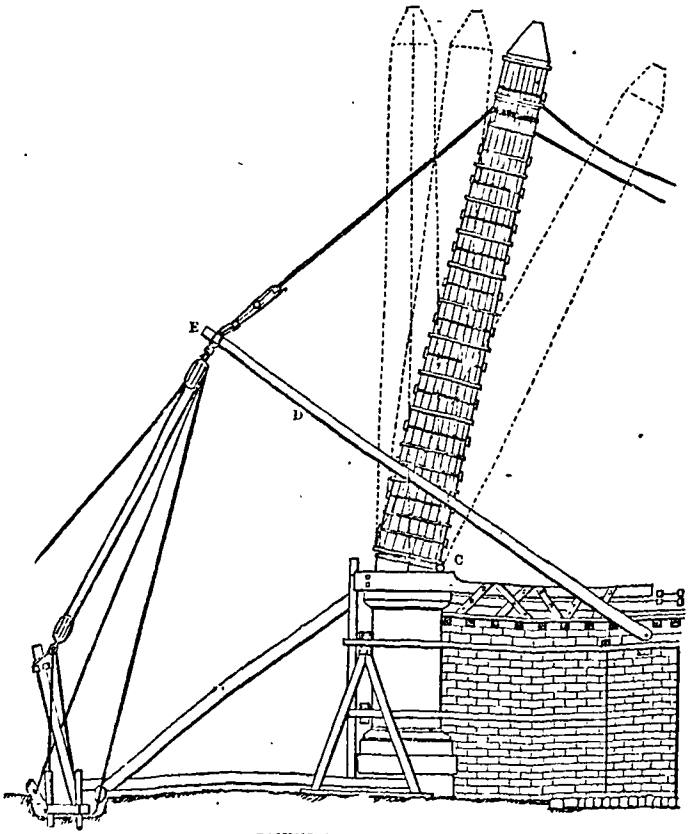


Fig. 1538. RAISING AN OBELISK.

prepared to receive them, and together could be moved upwards or downwards, in the manner of a hinge, so that when the ends at E were pulled down by the ropes of the windlass attached to them, the obelisk was advanced further into its perpendicular position; 480 artillerymen worked ten capstans, forty-eight being placed to each. Iron chains were placed around the top, and four others passed to capstans at the extremity of the inclined plane, for the purpose of holding the obelisk steady, and rendering its motion regular as it advanced.

The whole of the operations were admirably conducted, and some improvements were adopted which we do not find made use of by Fontana; the application of the lever, D, is a decided advantage.

The erection of a vase or statue on its pedestal is generally performed by three movements, one vertical, to raise the object to the required height, another to move it horizontally, and the third to fix it in its place.

The most simple method is by the use of tackle attached to the top of a mast, or two poles lashed together at a height sufficient to enable the object to be lodged where required: such a shear or support is represented in the cut; its position on the ground being established by pulling it upright, the base is hung directly over the pedestal; after which it may be lowered by means of pulleys at pleasure. The term shear is applied to the arrangements made in our dockyards by which the masts are hoisted into ships: one at Woolwich is an excellent example of this kind of tackle. The polyspaston of the Romans was no doubt a similar machine in every particular.

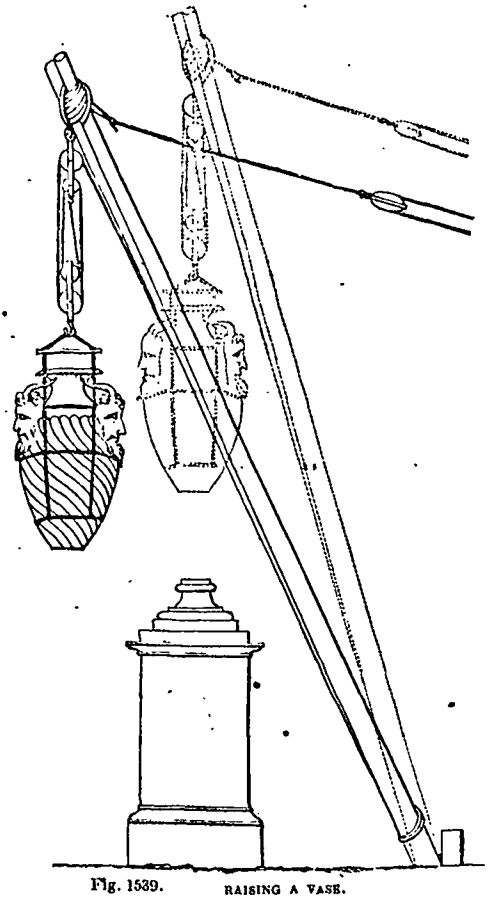


Fig. 1539. RAISING A VASE.

Tractorial machines, as they are termed by Vitruvius, consist of two movements, different and dissimilar from each other, but so agreeing that the operation is perfected by both; one is rectilinear, and the other circular, but neither alone can be made effectual for raising weights; when stones were raised for building purposes, the *forfices* or *forcipes* were sometimes used: and Piranesi in his "Antichità Romana" asserts that he found, in some of the ancient buildings, stones with holes cut in their upper faces, in such a form as to suit the dovetail shape of the modern Lewis or Louis; there can be no doubt but that this instrument was used by the Romans.

CHAP. XIII.

CARRIAGES FOR TRANSPORTING WEIGHTS, AND BOATS, ETC.

Carriages for transporting Weights and Boats, &c. — The daily work of a horse has been estimated as equal to that of five or six men; its immediate force may be somewhat greater, but it cannot work profitably for more than 8 hours a day when pulling with a force of 200 pounds, or 6 hours when exerting that of 260 pounds, and walking 2½ miles per hour: when drawing up a hill the horse loses much of his power, as he does when the carriage to which he is attached passes over a yielding or bad road. Whenever any large quantity of earth or other material is to be carted away, it is found profitable to lay down a provisional tram or railroad; but where this is not practicable, the carts or waggons should be well adapted to the use for which they were intended. The waggons generally employed on our railways whilst the works are in progress are without springs, and are now ordinarily drawn by locomotives or fixed engines, at the rate of 8 or 10 miles an hour.

The dynamical effect of a horse employed for raising earth-work up an inclined plane, the base of which was 60 feet, and the vertical height 40, was found only equal to a resistance of 410 pounds when travelling through a space of 72 feet in 1 minute, which is equal to 14,760 pounds raised 1 foot high per horse power per minute.

For the removal of the earth necessary to construct the foundation of the bridges built by Perronet, small carts were used having a triangular section in the line of their draught; each was mounted on a pair of wheels, and two attached together would be drawn by one horse: a part of the load rested below the axle, which passed through the middle of that

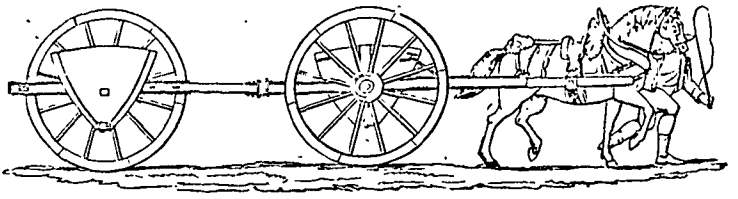


Fig. 1540. PERRONET'S CARTS.

part of the cart which retained it; and as the whole was nicely balanced and swung upon its centre of gravity, when it was to be discharged, a very small power only was required to turn it over and empty it of its contents.

The shafts and frame were of timber, and the axle of iron; the wheels were of considerable diameter, and placed wide apart, to prevent their being easily upset; the temporary or provisional roads being often far from level, this precaution was peculiarly

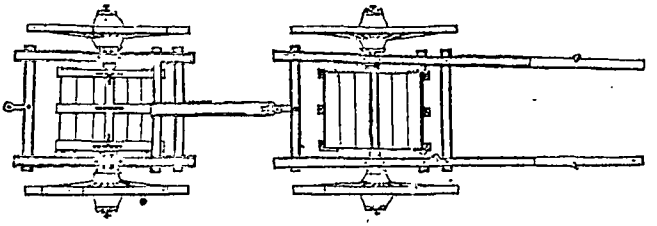


Fig. 1541. PLAN OF CARTS.

necessary. In the rear of each cart, and in the middle of the cross tie or brace, was an iron ring and pin, which allowed of another cart, having a pole instead of shafts, to be attached to it.

The transverse sections and end view of these convenient carts show the manner they were suspended, and the diagram between them exhibits the difficulty of overturning a figure so hung.

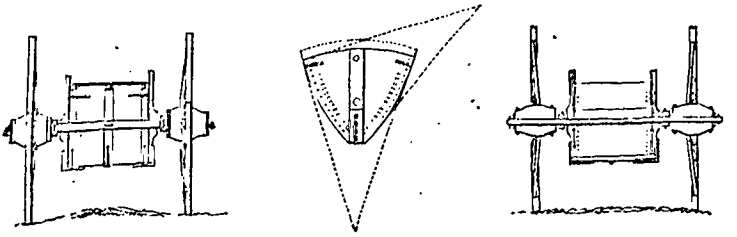


Fig. 1542. SECTIONS AND ENDS OF CARTS.

Two carts contained together about a cube yard, and were found extremely serviceable; they could be easily disconnected in case of accident, and attached with facility, before or after they were loaded.

The body of the waggons employed on the railroads for the conveyance of coals is made like the frustum of a pyramid, although in some instances the square form is preferred: about the middle of the last century iron wheels were introduced for the carriages employed at the coal mines near Newcastle, and they are now usually of cast-iron; the rim is made cylindrical, with a projection on one side, called the flanch, which keeps it upon the rail; the axles are of wrought-iron, and fixed in the centres of the wheels.

Waggons for conveying coals usually discharge their contents at the bottom, on which account they are preferred of this shape; the framework consists of two side soles fastened together by four cross sheths well bolted. The upright sheths and top framing are of iron, and the ends and sides are clead with deals bolted to the upright sheths; sheet-iron is sometimes preferred to the deals, when it is riveted on to iron uprights.

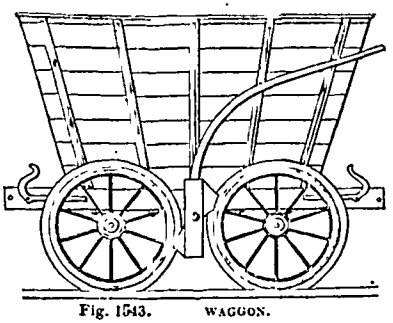


Fig. 1543. WAGGON.

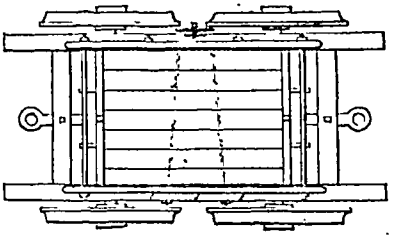


Fig. 1544. WAGGON.

Each carriage is provided with a break fastened to the side frame by a cast-iron stud; a wrought-iron pin is keyed into this stud, on which the break works, the pin acting as the fulcrum: these breaks or brakes were formerly called convoys, and were made of wood. Waggons of this description carry without heaping 55 cwt. of coals. The axles should always be made of scrap or malleable iron of the best workmanship, of about 3½ inches in thickness.

Trucks upon four wheels are sometimes used at the collieries for the conveyance of heavy material; they are of a simple form, and usually of timber; the main framing consists of three longitudinal pieces bolted down upon a timber axle, under which the wrought-iron axles are secured, upon which the wheels are placed. The

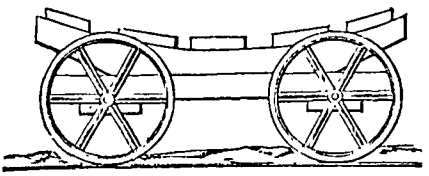


Fig. 1545. TRUCKS.

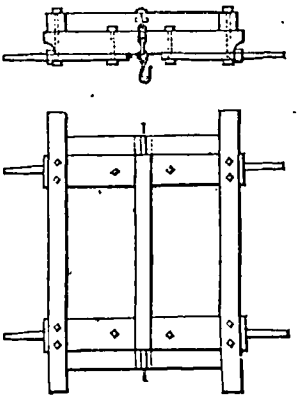


Fig. 1546. PLAN.

first cast-iron wheels had their rims case-hardened, wrought-iron tires were then adopted; and some had cast-iron naves, and rims with hollow iron spikes. The wheel now generally in use is made of wrought-iron entirely, though some have cast-iron rims hooped with wrought-iron; cast-iron is not found sufficiently strong where great speed is required, nor can they be considered safe against accidents.

On some of the northern railways the carriages are more simple in their form, and are so framed that they can be easily taken to pieces: the longitudinal bearers are mortised to receive the uprights, and the wheels run upon axles secured to the under side of the transverse timbers at the ends. In some cases, by

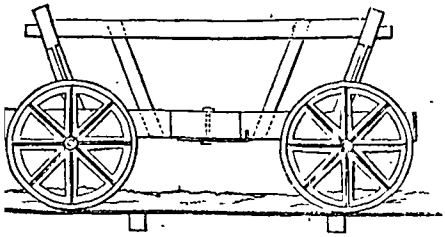


Fig. 1547. RAILWAY CARRIAGE.

turning a stop on each side, the bottom of the carriage is made to open and deposit its load without any additional labour. The flanch

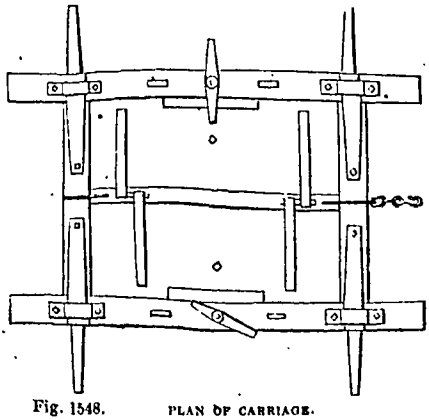


Fig. 1548. PLAN OF CARRIAGE.

of the wheels is about 1 inch deep, slightly bevelled off from the inner side to the outer, so that when the wheel is running in a straight direction, the edge of the flanch is kept about an inch clear of the rail, or from coming in direct contact with it: this is effected by making the tire, which is 4 inches broad, slightly conical, the inclination being about one part in seven or eight. Where the flanches are not bevelled or are too shallow, the carriages are very apt to run off the rails, and should they come in contact with a defective joint in a rail the same evil is likely to occur.

Waggons 6 feet in length and 2 feet deep are found convenient on railways for carrying earth and ballast, as well as the other materials required whilst the works are in progress. The plan shows the under side of the framing, consisting of two stout longitudinal timbers to receive the iron axles, upon which the wheels turn. The bottom of the waggon is further strengthened by iron plates, and a three quarter round iron bar passes from one side of the frame to the other, to hold them together in the middle, and to assist in supporting the load at the bottom. The uprights at the sides are mortised into the bearer at bottom as well as the top rail, and at each angle is an iron bolt that screws the whole together in the direction of its height. The ends are movable, sometimes sliding in grooves, at others merely pinned in their place.

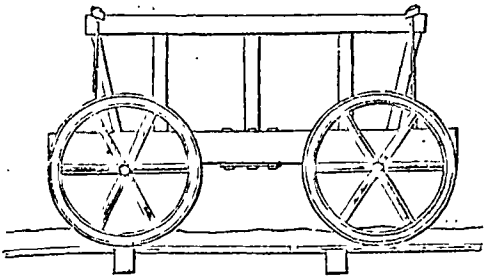


Fig. 1549. RAILWAY WAGGON.

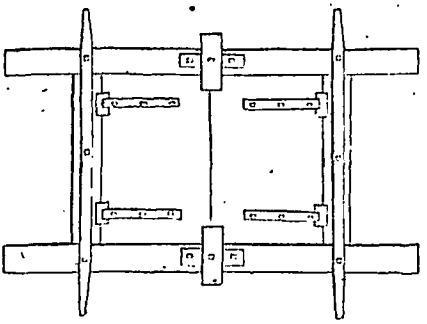


Fig. 1550. PLAN OF WAGGON.

In the construction of all kinds of railway carriages great attention should be paid to the centre of gravity of the load, for if too high their oscillation is considerably increased, which frequently occasions them to be thrown off the rails, even where the wheels have the proper depth of flanch: the revolving parts of the machinery in a carriage should be always so balanced that a smooth and equable motion can always be maintained.

In Italy carts of a different character are used for ordinary purposes, mounted above four cast-iron wheels, in such a manner that they can be tilted on one side, but the body being above the top of the wheels is objectionable.

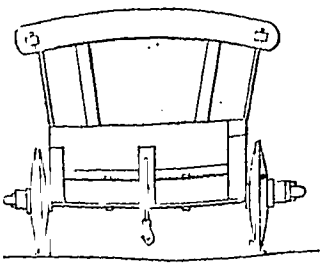


Fig. 1551.

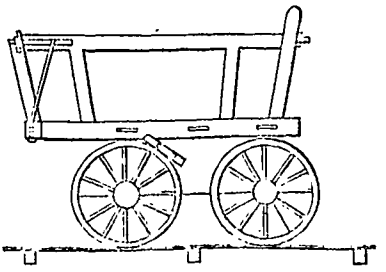


Fig. 1552.

CARTS IN ITALY.

Another method is sometimes adopted where low wheels are used, which only requires a stout block to be placed over one half the axle: the waggon or cart is hung upon the edge, which allows of its being tilted sideways for unloading. The side is hung either upon pivots or a strap hinge, so that it can be let down to accommodate the throwing out the earth or ballast it may contain: when the carriage is level, it is maintained in that position by a couple of irons, attached to the opposite side to that which inclines: these either hold within an eye or fasten upon a loop by means of a pin.

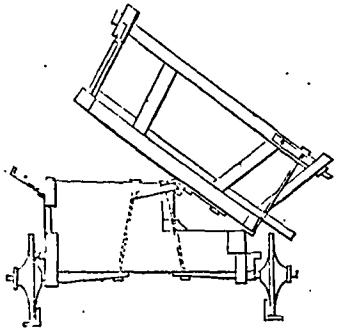


Fig. 1553.

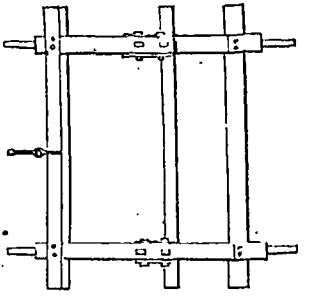


Fig. 1554. CARTS IN ITALY.

In Tuscany the conductor, seated behind the carriage, can, by a simple lever working in a groove upon the axles, tilt the waggon forwards, and deposit the earth it conveys down a

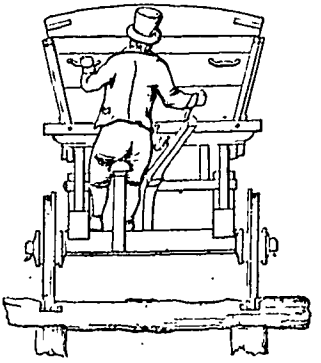


Fig 1555. END VIEW.

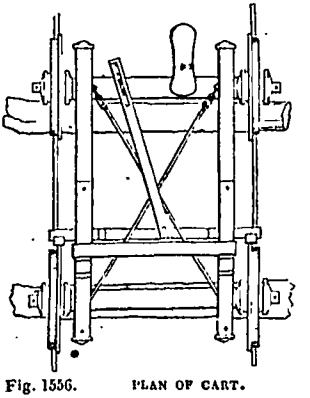


Fig. 1556. PLAN OF CART.

steep bank or slope, without any inconvenience or danger to himself: an iron groove passes obliquely from one axle to the other; in this the end of a crooked lever runs, which holds the bottom bearer of the carriage by a ring; when this is pushed forward, with a slight upheaving of the load, its action lifts the hinder part and inclines the front forward to shoot it out.

Railway Carriages. — Waggons for the transport of coals, as they discharge their load generally from the bottom, are made larger at top, or shaped like a hopper; they are sometimes of a more cubical shape, but this is not found so convenient.

In the example given, which is that in use at most of the northern collieries, the framework is put together with iron bolts, into which the uprights to receive the planks that form the sides of the waggon are mortised; the wheels are of cast-iron, and have wooden brakes fastened by a cast-iron stud. These waggons are about 9 feet in length at top, 6 feet 4 at bottom, and 4 feet in height, as much in width at the bottom, and will carry nearly 3 tons of coals.

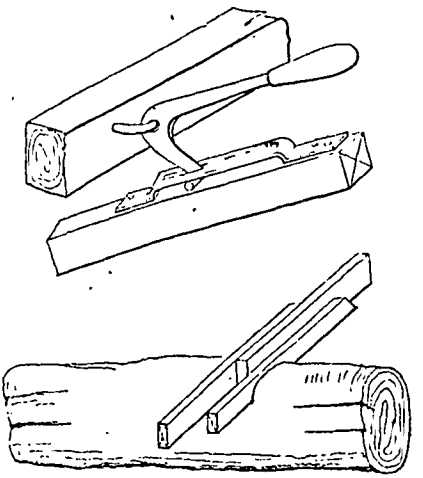


Fig. 1557. MOVEMENT OF CART.

The trucks used for the conveyance of merchandise consist of a platform or longitudinal frame, diagonally braced for greater strength, on which springs are placed, in order that the carriage may be kept as low as possible; one check of the guides over the axles project

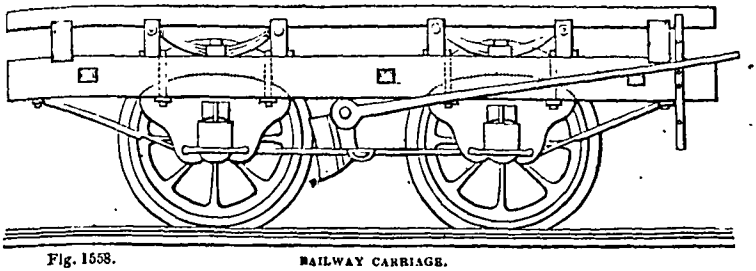


Fig. 1558. RAILWAY CARRIAGE.

upwards, and is on the inside of the frame, to which it is securely bolted. The dotted lines represent the checks of the chair, within which the guides slide up and down. These are carefully fixed, to prevent any twisting or oscillation, to which the framework would be

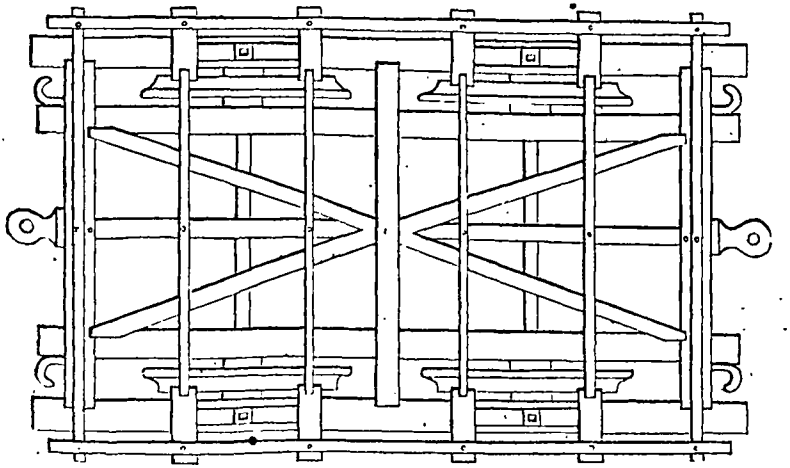
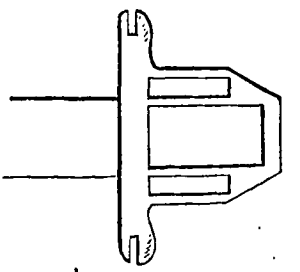


Fig. 1559. PLAN OF CARRIAGE.

subjected. These trucks on a railway 4 feet 8 inches in width have a superficial area of platform equal to 75 square feet, and generally carry about 4 tons weight.

The second class passengers' carriages have the same kind of frame, on which iron uprights support a curved top; they are partly inclosed, and the seats are arranged between the divisions. These carriages have sometimes a semicircular bearing on the axle by means of a chair, which is bolted to the framing of the carriage by two bolts, the under side of which embraces the lever half of the axles diameter, and is bolted to the chair above. Oil is poured upon the axle through a cup and small tubular passage which is sometimes made sufficiently capacious to contain a cotton wick which drops the oil upon the axle as it is required.

In many carriages the bearing is on the outside of the wheels, the end of the axle being diminished gradually towards its termination, where it is again increased to prevent its sliding. The chair is an iron box cast in two, se-



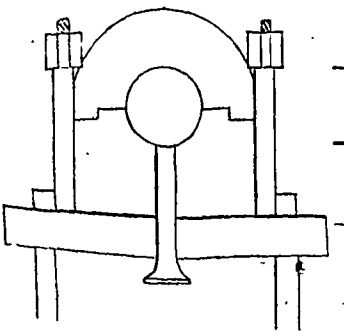
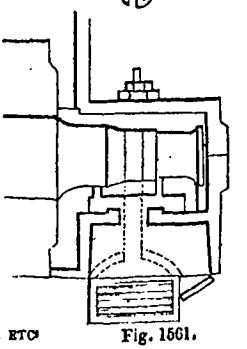


Fig. 1560.



AXLES OF CARRIAGES, ETC. Fig. 1561.

parated at the level of the diameter of the axle, or in the middle, where it is fastened together by iron bolts. The brass which surrounds the axle and is contained within the iron chair is nicely turned, and in the chamber above, which is cast in the chair, the oil is put, which drops over the axle, to destroy the friction; an inclined lid resting against the spring of the carriage allows it to be replenished as often as required.

The carriage spring has its bearing on the chairs, to which it is also attached by an iron bolt passing quite through the chair, and secured at the bottom by a nut: on the plan is shown the grooves which allow the vertical guides to work, that are attached to the outside of the carriage.

Thus the manner of fixing the wheels of railway carriages is the reverse of those intended for the ordinary road, where the wheels revolve on the axle; in the former, they are guided by the flanches, and as the carriage is not required to turn, it is securely fixed to it.

The bearing of railway carriages, on which the axle turns, in common waggons is placed within the wheels when they are outside the framework; in those constructed latterly upon an improved plan, the bearings are on the outside of the wheels, so that a greater width of framework is acquired, as well as elevation above the wheels, which raises the centre of gravity. The springs, which are made long and straight, are all placed above the frame, so that the platform, which receives the load, need not be elevated to an unnecessary height.

When the bearings in which the axle turns are placed outside the wheels, there is an advantage over the plan of having the journal or bearing inside, as well as less friction created; journals of wheels 3 feet in diameter may be reduced from 3¼ to 2¼ inches in diameter, which presents considerably less surface in contact. The journal of the axle requires to be turned with the greatest care, as any unevenness would produce considerable mischief: at the outer end it should be made a trifle more in diameter, and be provided with a collar, to prevent the axle from having any lateral movement.

In the nave of the wheel a square hole is bored to obtain a more perfect fit, and the end of the axle is wedged firmly into it: in all the common carriages the bearings in which the axle turns are placed inside the wheels when these are outside the framework, but in those built upon the improved principle, the bearings are placed outside the wheels.

For lubricating the axle, there is a small box placed directly over the bearing, having a small hole in the bottom through which palm oil or tallow may run upon the journal when the angles become heated; as the contents melt away, fresh ointment, as the mixture is termed, is supplied by lifting up the lid, which is kept closed by a spring whilst the carriage is in motion.

Buffing Apparatus is composed of round blocks or discs of metal or wood, which project from the ends of the carriages, and are commonly covered with cushions of leather; they are fixed to the ends of iron rods placed underneath the framing of the carriage and have a free motion inwards, where they press against an elliptical spring, when they touch or come into contact with those of the adjoining carriage: whatever may be the number of carriages in a train, the buffers are all made to stand in a line with each other, so that whenever any concussion takes place, the shock is conveyed throughout, and consequently materially lessened in its effect: the buffers are also made so that the springs serve either for pulling or pushing the carriages.

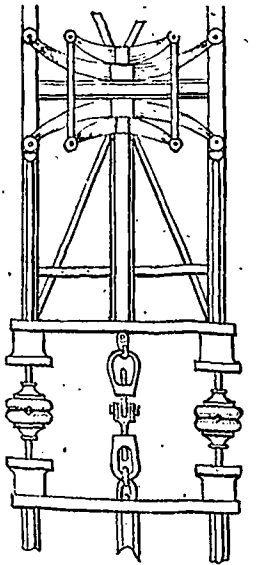


Fig. 1562. BUFFERS.

Several other kinds have been used, in which chain and screw shackles keep the heads of the buffers constantly in contact with each other; and some are furnished with spiral springs, with an iron rod passing from one end of the carriage-frame to the other, the buffer heads being connected by chains; in such the rod of the buffer at each end passes through a hollow tube, where it is surrounded by the spring, which presses against the tube, but does not enter it.

Air, from its elasticity, has been found to diminish the effects of concussion when confined in a cylinder, and acted upon by pistons fixed in the place of buffers.

Boats for the Transport of Stone, to form Breakwaters, &c. &c. — Suetonius (*in Claud.* c. 26.) informs us, that when Claudius built the harbour at Ostia, by throwing out an arm right and left, in order to form the pier which closed its entrance, he ordered the ship to be sunk which had brought the great obelisk from Egypt, and Pliny, lib. xvi. cap. 76., mentions that it was formed of immense timbers, one of which, a fir, was of prodigious size, and that nothing ever appeared at sea more astonishing than this vessel, 120,000 bushels of lentiles serving for its ballast. Granite columns of such dimensions as those which

ornament the portico of the Pantheon, must have required vessels or rafts of considerable size to have borne them across the Mediterranean: of their construction we have, however, but vague accounts handed down to us, but we have descriptions of many employed in the transport of the marble from Greece to Rome, and in some instances we learn that they were not calculated for their destined purpose.

De Cessart's Machine for throwing large stones into the sea consisted of a pontoon carrying an inclined plane made at an angle of 22°; this deck had a level platform, 6 feet in width, to carry the stone, which was placed on three rollers 6 inches in diameter, and

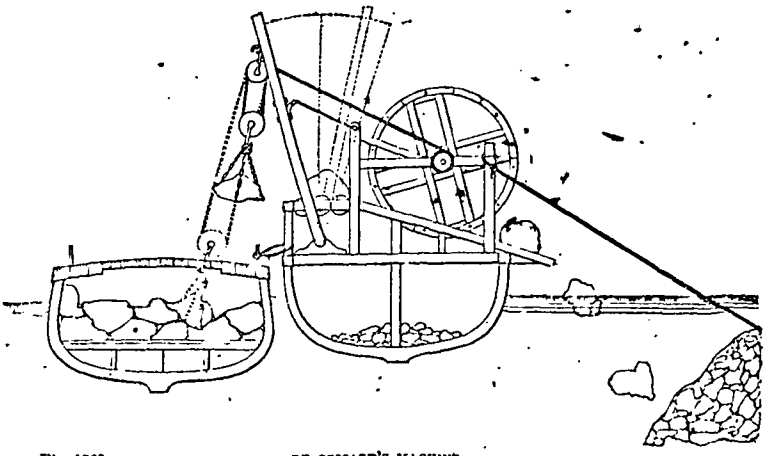


Fig. 1563. DE CESSART'S MACHINE.

which were hooped with iron: a gib moving on a pivot was furnished with pulleys, and kept in its place by two iron rods: two wheels and axles worked the ropes, the wheels were 12 feet, the axles 1 foot in diameter.

Iron chains first lifted the stone, brought by lighters or other vessels; the wheels were then turned till the necessary height was obtained, when the hook was detached, and the wheels worked, till the gib was in the position indicated by the dotted lines. It was then slightly unrolled, and the stones were placed on the three rollers; two men with levers pushed them forwards to the inclined plane, when they were allowed to slide forwards into the sea.

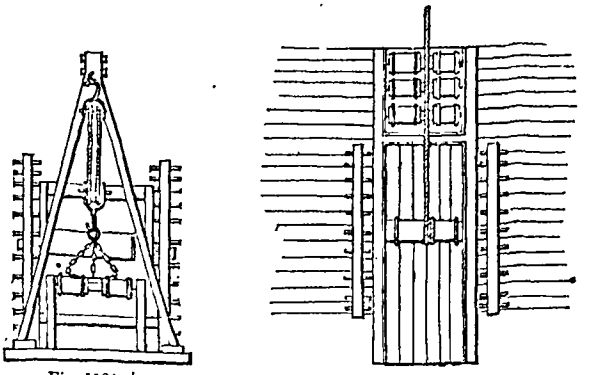


Fig. 1564. DE CESSART'S MACHINE.

The boats used for conveying the stone to the Plymouth breakwater were so arranged that they could be easily unloaded by similar tackle, and their contents be thrown into the places marked out to receive them. The transverse and longitudinal section through one of these boats exhibit the manner in which the stones were placed; each mounted upon a small carriage could be easily lowered by the inclined plane at the stern into the hold, out of which they could, by means of a windlass, be drawn up upon deck and lowered.

The arrangement of the ballast and stores of a ship, or its stowage, is of the greatest importance, as we know that the sailing of a vessel depends on the situation of the centre of gravity, which is determined by the disposition of the movable weights on board; to this subject Daniel Bernouilli, Euler, Bossuet, and others, directed their studies; they have shown us the manner in which such weights affect the position of its centre of gravity, the stability of which is increased or diminished according as it is lower or higher in the ship; to place the weight, then, as low as possible is necessary; when the

stability is required to be increased, the nearer the stones are deposited to the middle of the ship, in the full parts of the body, the more effectually will this be accomplished.

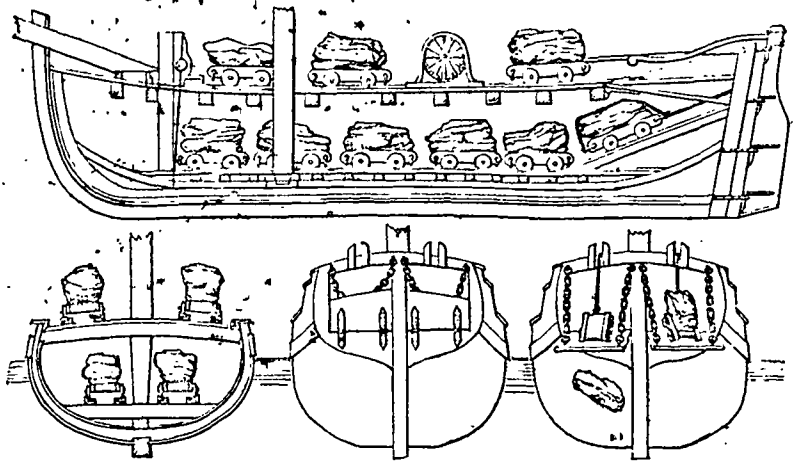


Fig. 1565. BOATS FOR THE BREAKWATER.

Machines, &c. for proving the Strength of Materials, differ in their arrangement according to the strains that are to be tested. We shall consider, first, what materials may be drawn asunder by a force acting at the end; secondly, how they may be compressed by a force acting in the same direction; thirdly, how they may be strained laterally, one part being supported, and the strain immediately applied at the point of support; fourthly, how they may be similarly affected transversely; fifthly, how they may be twisted; sixthly, how they may be strained by any two or more of the above forces, and also how they may be strained by an internal pressure, as is the case with hydraulic cylinders, water-pipes, &c.

First, with regard to the resistance to extension in length, arising from the direct cohesion of the fibres or particles of matter; this kind of strain in timber requires some care to be observed in ascertaining it, as the fibres are liable to be injured or destroyed when roughly experimented upon: one of the best machines for the purposes here required is described by Mr. Peter Barlow, in his Treatise on the Strength of Materials, and who made experiments with it upon a piece of wood 12 inches in length, the square ends of which were 3½ inches, and the side of the square 1½ inches; the intermediate part, 5 inches in length, was by means of a lathe reduced to a third or a quarter of an inch in diameter, the other cylindrical portions being left ¾ inch in diameter; these pieces, so prepared, were placed at the top of the frame, and passed partly through a circular hole in an iron frame, laid horizontally upon two upright supports; the sides of this frame were then screwed tightly together to prevent the piece of prepared wood being pulled through; a couple of iron boxes were placed upon the lower square, and screwed tightly up; near the top they had two semicircular holes, correctly fitted to the larger part of the cylinder; these were shut by passing bolts through them, which perfectly secured the two shears; the head of the piece of timber was placed above the collar, the upper large cylinder being retained in the hollow iron chamber at top prepared to receive it; and the lower square end, inclosed in the two iron boxes, the hook of the scale was passed through the circular hole, and the scale, being wedged up from the ground, was loaded.

Among many experiments, the following results have been obtained, the smaller cylinders being reduced to what they would have been on square inch bars, it being assumed that the strength is proportional to the section of fracture:—

Box	20,000 pounds per square inch.
Ash	17,000
Teak	15,000
Fir	12,000
Beach	15,500
Oak	10,000
Pear	9,000
Mahogany	8,000

Of the Stiffness of Beams supported at one end: as it is difficult to fix a piece of timber in this manner, so that it will not be liable to extension beyond the point of support, there is a great difference in the results of the several experiments that have been made on the subject.

The beam which has one end placed in a wall and loaded at the other end will be deflected from its horizontal position into an oblique direction, and Mr. Tredgold gives for

	Specific Gravity.	Length in Feet.	Breadth in Inches.	Depth in Inches.	Deflexion in Inches.	Weight producing Deflexion in Pounds.	Value of constant Quantity.	
Oak - -	·922	4	2	2	1·176	112	·105	6
Riga fir - -	·537	4	2	2	1·34	112	·12	

The deflexion becomes greater as the distance A C is increased, and the equation given when a beam is fixed in a horizontal position, $\left(L \times \frac{b \times W^{\frac{1}{2}}}{0{\cdot}6}\right)^{\frac{1}{2}} = D$, and $0{\cdot}6\ D = B$.

When the piece of timber is inclined, and c is the angle of inclination, $\left(L \times \frac{b \times \cos.\ c \times W^{\frac{1}{2}}}{0{\cdot}6}\right)^{\frac{1}{2}} = D$, and $0{\cdot}6\ D = B$.

The value of b for oak being ·105, and for fir ·12; the deflexion calculated as $\frac{1}{10}$ inch per foot in length. A beam fixed in the before-mentioned position has its fibre in the same state of tension as when supported in the middle and loaded at each end, its length being in one case double what it is in the other: when resting on a fulcrum or support in the middle, and acted upon by two weights at the end, it is almost in the same condition as the force AB, excepting that it has a double strain in contrary directions. To make the necessary experiment, Mr. Peter Barlow employed a block of hard wood, 18 inches long and 12 inches square, which was cut through at about 5 inches from each end for the convenience of forming a mortice or hole 2 inches square, and as much in depth; the two parts of the block were then screw-bolted together, and an iron socket 2 inches square on the inside, made to fit the holes, was inserted in the mortice; the block was fixed by wedges into a wall, so that it was quite firm and steady. The pieces of timber tested were reduced to a scantling of two inches square, and made to fit tight into the iron socket, upon the other end of which the weight was suspended.

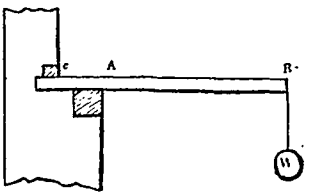


Fig. 1566.

Of the Machines used to ascertain the Resistance of Materials to a crushing Force. — The exciting force here acts directly in the reverse manner to that we have already described, and we have also to take into consideration the state of the material acted upon, whether it is too short to bend, as well as when its length is considerable with regard to its other dimensions: in the first case, small pressure would crush it; in the other it might bend, and afterwards alternately break, by a force somewhat similar to that exerted by a transverse strain. Experiments were made upon the crushing force by Rondelet, which are detailed in his *Art de Batir;* he states that a piece of oak whose base is an inch square would require 5000 or 6000 pounds weight to crush it, and a similar piece of fir would bear the additional pressure of another 1000 pounds.

Mr. Rennie found that a cube of English oak an inch square required only 3860 pounds to crush it, which result materially differs from the other, and leaves us still in considerable doubt upon this subject. Screw-presses and long levers have been made use of for testing materials, and to ascertain the exact crushing force; both methods might possibly be employed with advantage, and the results calculated from the practical effects.

The Hydrostatic Press is a machine by which prodigious force can be obtained, and is frequently used to cut through bars of iron, as well as to press paper, cloths, and other materials into a smaller bulk. A solid cross beam or piece of timber is fixed upon the two upright posts A, which are either let into the ground or framed into a sill at the bottom, and another, E, laid in an horizontal position, slides between the upright timbers; between this and the top the articles to be compressed are laid. The horizontal timber is supported on the under side by the piston D, which works in an air-tight cylinder F, at the bottom of which is a small pipe or tube b of much smaller bore; the other end of this tube enters at the bottom of a forcing pump L, and when the piston in the latter is pressed down, the water in the cylinder is forced under the piston which carries the horizontal timber and occasions it to rise. The difference of the size or area of the surface of the small tube, compared with that of the rising piston, constitutes the power; for if the sectional area of the tube be $\frac{1}{2}$ inch, and that of the rising piston 1 foot, as 576 to 1, or as 144 square inches to $\frac{1}{4}$ inch: and supposing a pressure of a ton weight to be exerted on the handle H of the

pump, the piston in the air-tight cylinder will press with a power equal to 576 tons: this power has no limits, when materials can be found strong enough to make the machine. Within the space or area of 100 inches and 1 foot in height, a power equal to 500 or 600 tons may be easily directed against any substance that may require pressing, tearing up, cutting, or pulling asunder.

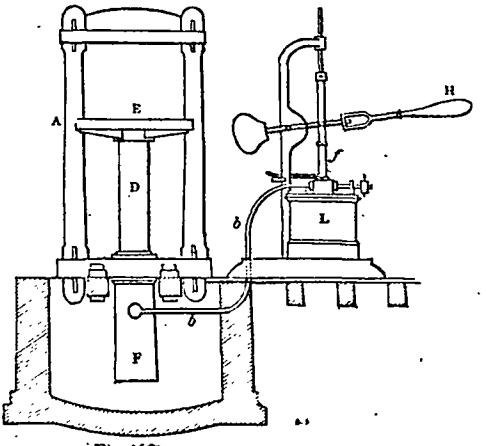


Fig. 1567. HYDROSTATIC PRESS.

The operation of this press is easily understood by supposing the pump cylinder and connecting pipe *b* to be filled with water, and an adequate supply contained in L: when the handle of the lever H is raised, it lifts the piston rod *f*, which would leave a vacuum beneath if the atmosphere did not force the water through the lower valve of the pump; the lever being then pressed down, the piston rod, by descending, diminishes the capacity of the pump, which causes the lower valve to close, and forces the water through the pipe *b* into the cavity of the great cylinder F, where it raises the piston D, together with the table E, a distance proportional to the quantity of water which has been injected: on the rise of the piston in the pumps, the descent of the upper valve prevents the return of the water, and consequently the fall of the cylinder D. There is a discharge valve to relieve the action of the press, and which permits the water that escapes to pass again into the cistern at L, when the table E again descends.

We have only described the action of a single pump, but where great power is required, a number worked by double handles are made use of; in which case particular caution is required to insure accuracy and to prevent leakage.

Previous to the blocks and ropes being used at the Menai bridge for hoisting the several parts, their strength was tested by a load of 50 tons placed in a square box: the frame was made of timber, the posts of which were 40 feet in length and 15 inches square, strongly framed both at top and bottom: two capstans placed at a distance were attached to the main falls, which passed through a pulley at the bottom of the frame, by which means the loaded box was lifted off the ground, and every portion effectually proved. The tackle by which the main chains of the bridge were hoisted to their respective positions was first put to the test of supporting 50 tons.

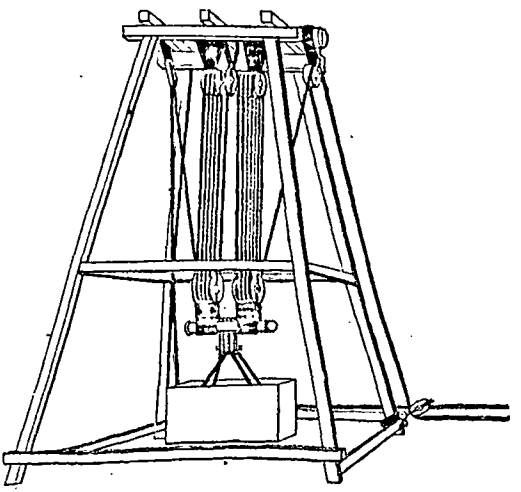


Fig. 1568. PROVING ROPES, USED AT MENAI.

In the machines for proving the iron work, the bar upon which the experiment was to be made was secured at its two ends, in the same manner as the blade of a pit saw: the power was obtained by three cogged wheels working in as many pinions; the radius of the first was 1 foot 10½ inches; of the second, 2 feet 6¼ inches; and the largest, 3 feet 6¾ inches: the diameter of the largest pinion was 13¼ inches; and the other 10$\frac{7}{16}$ inches.

The length of the bed of the machine was 12 feet 10½ inches, and the diameter of the axis of the largest wheel 8½ inches: the levers and weights that measured the strength were adjusted underneath the machine, the end view of which is shown at the top of the figure; the diameter of the cylinder was 8½ inches.

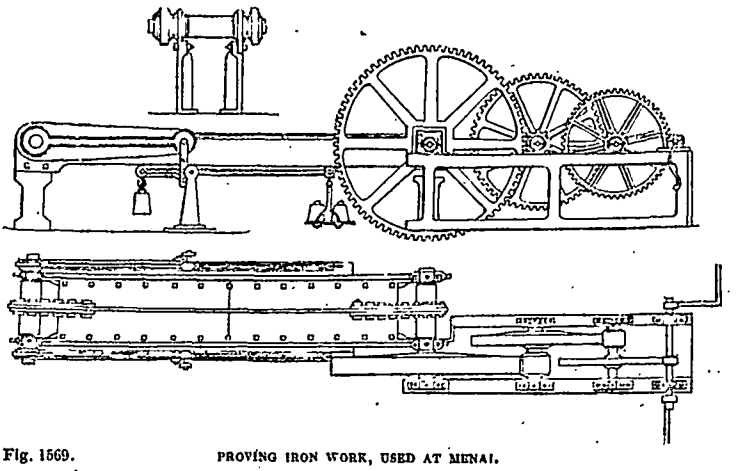


Fig. 1569. PROVING IRON WORK, USED AT MENAI.

Machine for bending Iron Plates is of the greatest service for the manufacture of boilers: on the left of the figure are two riggers, one tight and the other loose, for driving the two cylindrical rollers, the speed of which is regulated by the spur-wheel and pinions; on the right is the fly-wheel placed on the driving shaft, which maintains a steady motion when the machine is in use. The curvature to be given to the iron plate is regulated by a large screw attached to each cylinder, which brings them nearer, or drives them farther from each other, according to the required bend.

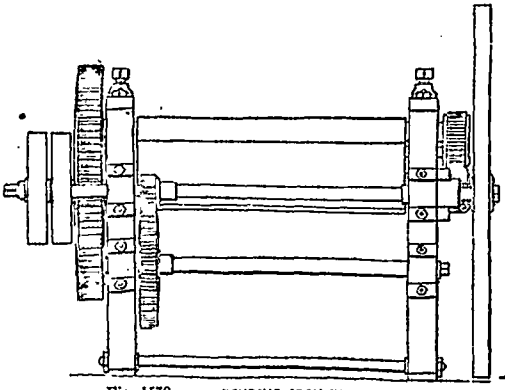


Fig. 1570. BENDING IRON PLATES.

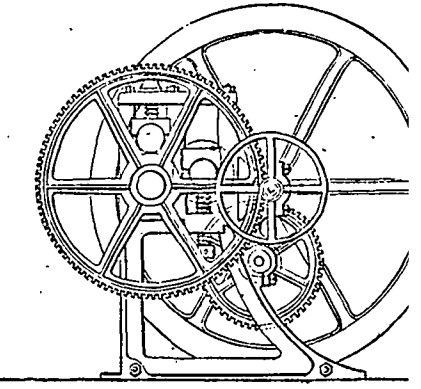


Fig. 1571. SECTION.

Machine for making Screw Bolts. — A backward and forward motion is given to a hollow shaft by three driving pulleys; when the strap is on that to the left, the spur-wheel and pinion put the machine in motion, and communicate it to the chuck which holds the steel

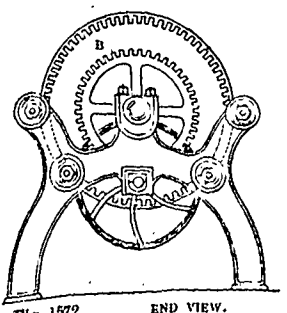


Fig. 1572. END VIEW.

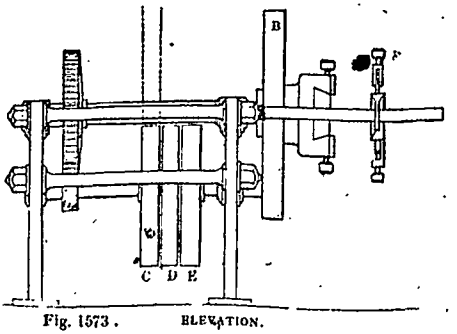


Fig. 1573. ELEVATION.

cutters; and after the screw has been cut, by placing the strap on the other outside pulley, the great internal wheel is made to revolve on the lower shaft, and draw the screw back to its original position: when the strap is put over the loose pulley in the centre, the machine does not produce any working effect, but is in the condition of perfect rest. In the section, the cutting of the screw is seen passing through the upper part of the chuck, and these are removable when required. The bolts which are to be screwed are held by a sliding frame, shown on the guide bolt, opposite the chuck in the elevation.

The two end views of the machine exhibit the iron frame as well as the gearing, and when a screw is to be formed, all that is requisite is to place the bolt in the sliding frame, and present it to the action of the die or cutter in the chuck, which, as it is turned round, forms the thread.

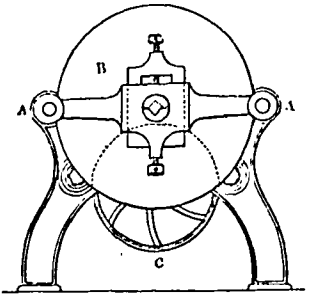


Fig. 1574. END VIEW.

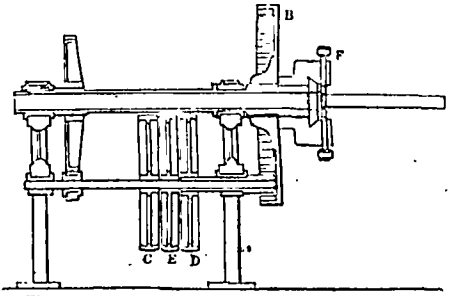


Fig. 1575. SECTION.

The end view of the machine shows one of the two frames that support the works, as well as the plummer blocks in which the two spindles marked A, A turn: the wheel marked B reverses the motion when it is required by the application of the loose pulley shown at E: C is the pulley which communicates motion to the spur-wheel at B: F is the frame into which the bolts are placed which are to have their ends made into screws.

The Lathe has of late years received so many improvements, that it bears no resemblance to the long lath or pole which was fixed at one end to the ceiling or wall of the workshop, and had the other moved by a cord passing over a pulley, and carrying the mandrell, which was moved by a board or treddle: on raising the foot, the spring of the lath caused an opposite rotation, which was again reversed by the pressure of the foot, causing the lathe to work as a drill, the cutting taking place only during each direct rotation.

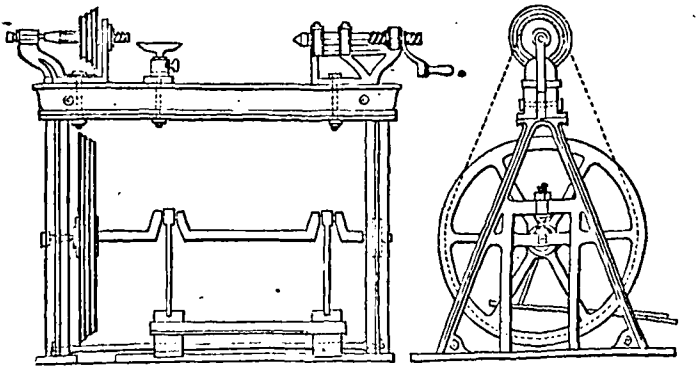


Fig. 1576. FOOT LATHE.

The lathe now consists of a horizontal bed, formed of two parallel bars of wood or metal firmly united together: to this are attached two puppets, one of which carries the mandrell and pulley, which is fixed in its place, and the other the back centre, which slides between the double bed, or along a single bar introduced for the purpose. The rest also slides on the bed, which supports the cutting tool, and underneath is an axle with a crank; to the former is attached a fly-wheel with a groove to carry the band, which passes over the pulley to the mandrell; to the crank is attached the footboard by an iron bar, which produces the motion to the fly-wheel and the other parts of the lathe.

Lathes are now generally made with cast-iron sides of a triangular form, bolted or screwed together at the iron flanches at top: the puppet on the side next the end view of the lathe is firmly secured by a bolt with a square head which passes through an iron

block under the bed of the lathe, where its end, with a screw cut upon it, receives a nut: the rest may be turned in any direction, but is fixed in its place in a similar way to the back puppet; the front puppet is also secured by a screw and nut, and has a motion along the bed when required: the chucks, formed of brass, are tapped and screwed on to the mandrell, with a hole in each to receive the wood to be turned.

Previous to the application of the slide rest to the lathe, the tool was held by the workman and entirely guided by his skill, and in turning the shaft of a column, it was scarcely possible that his unaided efforts could bring the whole into the true frustum of a cone, or that he could set out the swell or entasis at a certain portion of its height with the requisite precision: but when the principle of sliding the rest which held the tool for cutting was introduced, the shaft could be turned with extraordinary correctness: the cutting instrument in this new arrangement is held firmly and securely, and made to progress in a definite direction by means of a slide, the motion being communicated by a handle that turns a screw: two such slides produce a motion along as well as across the work, and so nicely is this arranged by turning the screw handles, that it is scarcely requisite to look at the operation as it goes on.

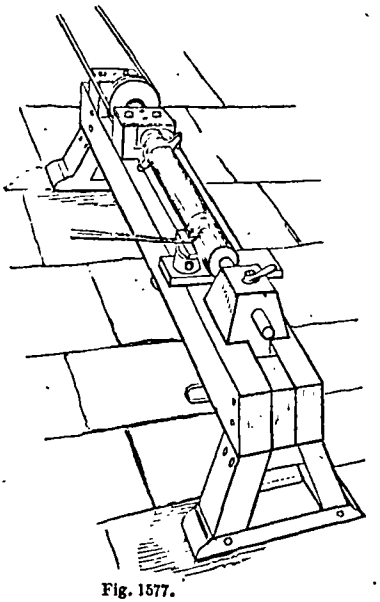


Fig. 1577.

Mr. Henry Maudsley contrived a *self-acting slide rest*, which has produced great improvements in every kind of machine: a piece of iron is attached to the work at one end, and turns round a star wheel at the end of the screw that moves the rest, which at each revolution of the lathe turns the screw and moves forward the slide rest, which carries the

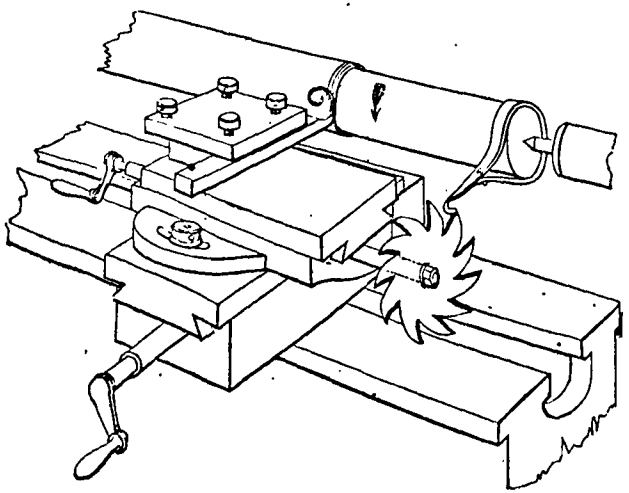


Fig. 1578. SLIDE REST.

tool onwards by degrees until the whole is very accurately turned, without the constant attendance of the workman. This ingenious contrivance has been applied, as we shall hereafter see, to a variety of other purposes.

Drilling machine is far more serviceable than the ordinary bore, and indispensable when the heavier kinds of iron work are to be drilled. The winch or handle is carried by two standards, and may be turned by three men; this, by means of a bevelled wheel, turns another placed horizontally, through the centre of which the drill shaft passes freely, and descends as the drilling proceeds. The drill at top, surrounded by a collar, is worked by a rack and small pinions attached to another wheel, over which passes an endless chain, which when pulled raises the rack and drill shaft; it is supported by a ratchet-wheel

and spring fall. Two iron standards passing from a pit in the floor of the manufactory support a table at any required height, on which the iron work to be drilled is laid; the drill is inserted in a socket at the bottom of the shaft, where it is secured by a bolt.

The portable Hand Drill is a similar machine, and found very convenient for a variety of purposes, particularly where the work to be drilled is difficult to move. A frame supports the upright spindle which carries the drill; on the top is a screw, by which it can be raised, and the revolving motion is given by two small bevel wheels placed at right angles with each other; these are turned by a small fly-wheel, to the rim of which is affixed a handle for working it; at the same time, a slight revolving motion is given to the upper handle, which causes the drill to descend.

The Foot Drill differs only in the mode by which the upright drilling spindle rises and falls; the examples already given are self-acting; on this it is performed by the pressure of the foot.

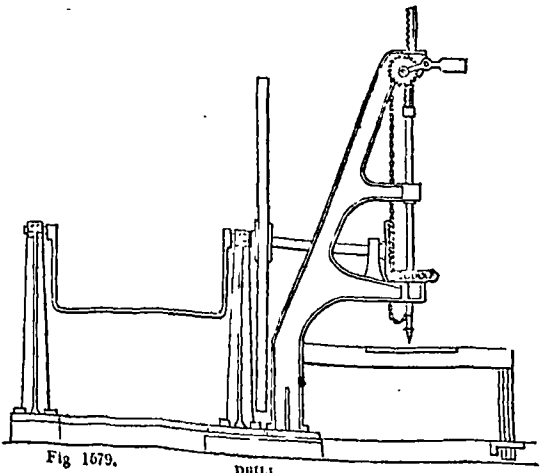


Fig 1579. DRILL.

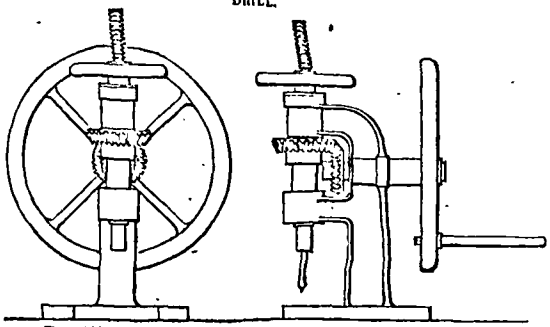
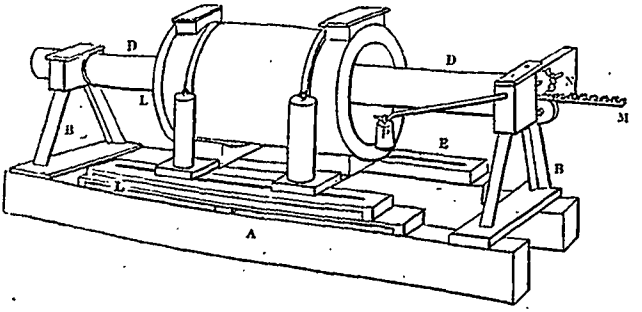


Fig. 1580. HAND DRILL.

Machines for boring or upright drilling were some years ago much employed in the preparation of timber water pipes. In the work by Belidor before alluded to, the tree to be bored is mounted upon a truck or wheel carriage, and well secured in its place: a water-wheel gives motion to a vertical spindle, which by means of a trundle and face-wheel moves round a horizontal bar that carries at one end the auger, by which the boring is effected: as this revolves, motion is given to another wheel, around the shaft of which is attached a rope that draws the carriage forward on which the tree is placed, as fast as the borer cuts its way: when the whole is cut through, the carriage is drawn back, and the process is repeated with a larger auger, and so on, until the whole is of a sufficient diameter.

In some machines the tree was made to revolve, and the cutter was fixed: the tree was in a vertical position, and in other instances the core was cut out whole; this was performed by employing a hollow cylinder, armed at the extremity with a circular saw, of the trepanning form, the cylinder being made to rotate as the saw cuts its way: the core entered the hollow of the cylinder as the latter advanced, and was thus preserved. Stone pipes were so cut that the block of stone was set nearly upright, and in the centre of the intended pipe a block of wood was fixed, with a hole drilled in the middle to receive the pivot of a perpendicular axis or spindle, considerably larger than the intended pipe, and of a triangular or square form; this revolving, performed, by means of the cutter which was attached to its end, the centre operation.

The horizontal boring Machine used for metal cylinders consists of a piece of iron called a cutter-head, which slides upon an axis, and has the knives or steelings which perform the boring fixed into it. The cylinder to be bored is firmly secured upon a frame prepared to receive it, and the cutters are advanced by means of a hollow cast-iron tube, on each side of which is a longitudinal groove or aperture: the cutter-head consists of two parts, viz. a tube fitted upon the axis with the greatest accuracy, and a cast-iron ring fixed upon four wedges; on its circumference are eight notches, into which the cutters or steelings are held by wedges; the slider or cast-iron ring is prevented from slipping round by two short iron bars put through the axis, and passing into notches cut in the ends of the sliders. The



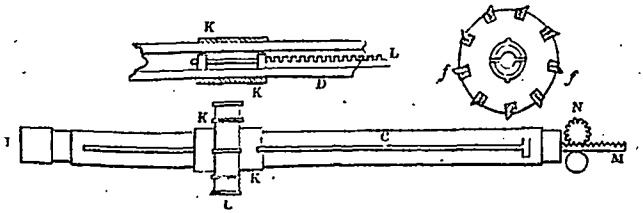
A. Sills. D. Cylindrical axis. L. Cylinder to be bored. N. Pinion.
B. Frame. E. Iron supports. M. A rack. P. Weight.

Fig. 1581. BORING MACHINE.

rack is moved by the teeth of a small pinion, and maintained in its place by a roller underneath it, both axes of which are supported by the iron framing.

By means of a lever put upon the square end of the axis, which is loaded by a weight, the pinion is turned round, giving to the cutter a constant tendency to draw through the cylinder. The axis on which the cutter is placed revolves, and the accuracy of the machine, depends upon its being truly turned, and on the centering of its pivots and gudgeons.

There are several varieties of boring machines, and other contrivances for drawing the cutter through the cylinder: one consists of four wheels, one of which is fixed at the right-hand extremity of the bar; another pinion takes the place of the rack, on which is a screw working in a female screw fixed to the cutters: below the second pinion is a third, fixed on a horizontal axis parallel to the long bar, and having the same number of teeth; a fourth pinion is placed at the other end of the axis, and is driven at the end of the hollow axis. The first pinion has twenty-six teeth, the fourth thirty, and the second and third



K K. Cutter heads. L. Wedges. f f. The cutters.

Fig. 1582. CUTTER OF BORING MACHINE.

the same number: as the axis revolves, the first pinion fixed on its extremity drives the fourth, which by means of the third fixed on the same axis with it gives motion to the second; the second pinion being fixed to an axis within the other unscrews the screw at the other extremity, and advances the cutter along the cylinder: this screw has eight threads in an inch; sixty turns are consequently required to cut an inch.

Some care is required in fitting the cutters, which are secured by wedges, and adjusted by turning the axis round, to see whether they describe the same circle; the boring commences by putting the axis in motion, and the machine then requires no further attention than observing if the weight is lifted up as often as it descends by the motion of the cutters; when the cylinder has been once passed through, they are again set to a large circumference, and proved the second time, and so on until the boring and polishing is complete.

During the last few years great consideration has been paid to the manufacture of every kind of tool that could perform the work of the mechanical engineers, with more immediate effect and economy of time than could be produced by mere manual labour; all these tools, or rather powerful engines, used for the construction of others, are admirably described, accompanied with engravings sufficiently large to explain all their parts and proportions, in an edition of Buchanan's Millwork, edited by Mr. George Rennie: this elegant work, containing also practical and very valuable observations on the sharpening of tools by Mr. James Nasmyth, should be in the hands of every engineer; the latter writer, in an essay in the appendix, shows us most clearly that in forming and setting a cutting tool, so that it rightly performs its work, it is necessary that it be so placed that its end forms the least possible angle with the surface to be cut; it must consequently be nearly parallel with the face or plane it is to act upon

The workshop of the engineer at the present day contains machinery of the most costly

kind, and the means now adopted to furnish that which the growing wants of our manufacturing and industrious population require, differ materially from those in use half a century ago, when all work was performed by manual labour: an estimate of the value of these leviathan tools, consisting of turnery lathes, planing, riveting, boring, screw cutting, plate bending, punching machines, and others in a large establishment, would show the enterprise and skill which the demand for steam-engines and machinery employed in commerce and manufactures has called forth.

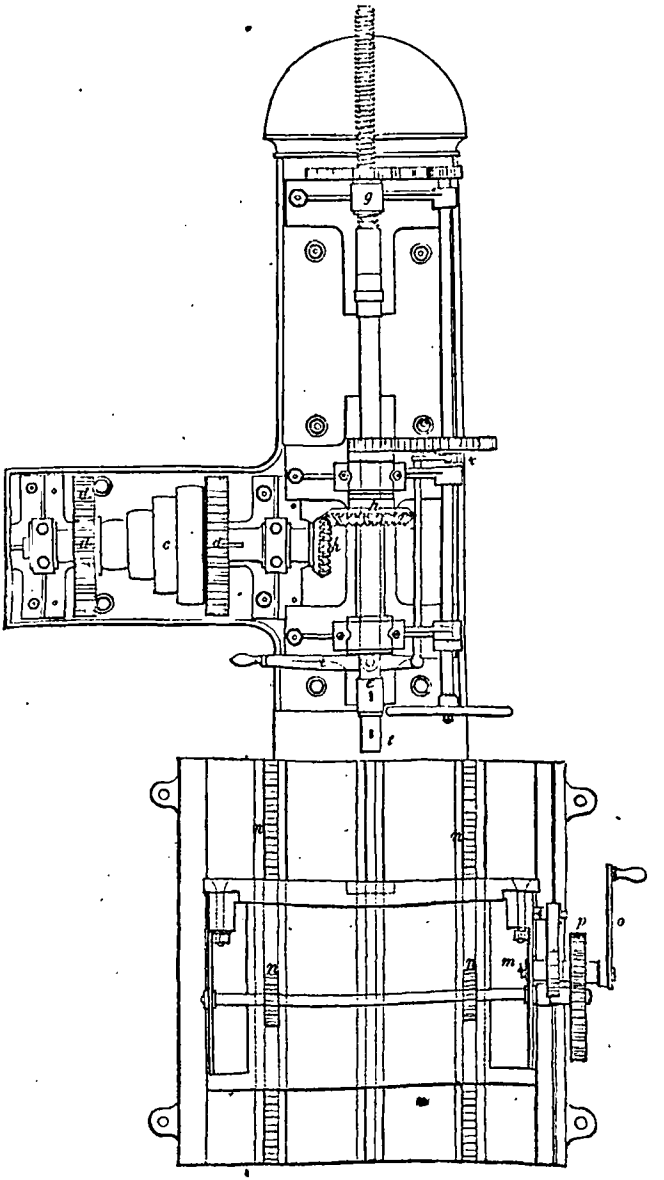


Fig. 1683. CYLINDER BORER.

For boring the Cylinders of Steam-engines a powerful and very accurate machine is required: the cylinder is sometimes placed in a horizontal position, and when fixed the cutters are made to revolve, and advance forward by the force of machinery; in boring

guns, as the gun moves round, its exterior surface is turned quite true by means of a lathe. Musket barrels are similarly bored and turned by the several motions of the common turning lathe, one machine finishing three barrels per hour.

The vertical boring machine, now generally preferred, has the motion given to the upright or drilling bar by three driving pulleys shown at *c*, the speed of which is regulated by the spur-wheels and pinions at *d*. When the drilling bar is required to be lowered or raised, it is effected by the spur gear at *f*, immediately above the nut *g*, in which the screw works.

The plan of the machine shows a slide at *m*, which carries the work, and the table upon which it rests is raised or lowered at pleasure by the racks and pinions at *n*, *n*, worked by the handle at *o*, which communicates with the spur-wheel and pinion *p*: within this is a ratchet-wheel. In the elevation at *l*, is a small lever or handle, for throwing the small clutch at *k* in and out of gear, and the drilling bar is marked by *e*, *t* being the boring part of the bar, which can be made to bore a cylinder to the depth of 24 inches from ½ an inch up to 14 in diameter. In some machines an alteration of speed is obtained by means of two shafts, one of which has a wheel working in a pinion, and the other a pinion on a wheel.

A boring machine may be defined as contrived for working a borer or tool, which, by a rotary motion on its axis, cuts out a hollow cylinder in any substance it is applied to; the whimble, the drill, the pulley, and the bow, are all of this class, but we now only use the term to an apparatus for boring large cylinders more accurately, and in shorter time than can be performed by manual labour. The method formerly adopted for boring cylinders for pumps was an horizontal axis turned slowly round by a mill, at the end of which the borer was attached; the cylinder fastened to a carriage, made to slide in the direction parallel to its axis, was drawn forwards by means of a weight that could descend. The defect of this system was the liability that the rectilineal motion of the carriage would be transferred to the cylinder, and cause it to be bored improperly. Smeaton remedied these evils to a certain extent, by introducing a steel-yard mounted upon a movable wheel carriage, which traversed with the cylinder, and by suspending the weight of the cutter and boring bar from it.

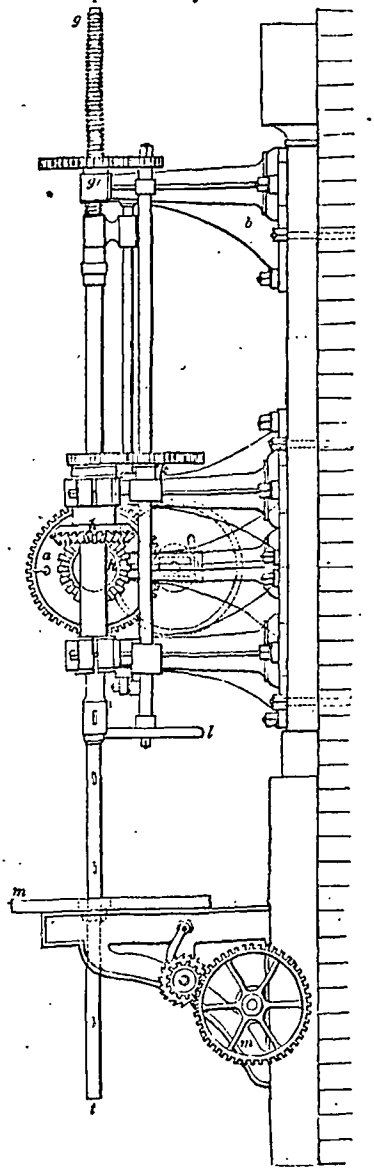


Fig. 1584. SIDE ELEVATION

Machines for punching Boiler Plates with the greatest possible accuracy are now made use of, instead of the ordinary punching machine, which required the rivet holes to be marked out by a template with white paint, and afterwards brought under the punch: the plate is now affixed to the top of a movable table, and when it is adjusted to the distance required between the rivets, the rest of the work is performed by machinery. In the Royal Dockyard at Woolwich, several of these punching machines are at work in the shop where the steam boilers are wrought.

The plate to be punched being laid upon the movable table at *k*, and secured by clamps, is brought over the die frame at *i*, where it is also directly under the influence of the punch; the whole of the machinery is mounted within a strong iron frame, and motion is conveyed to it by the tight and loose riggers at *a*, *a*, at the side of which is a fly-wheel for regulating it; on the spur-wheel at *m* is a tappet or pin, which, coming in contact with a small lever, as the spur-wheel turns round, advances by a connecting rod the table shown at *k*, which runs along a railway provided for it by means of two carriages attached to the

travelling table, and supported on the notched bar *n*: holes are now punched in plates of sheet iron or copper with great accuracy and rapidity.

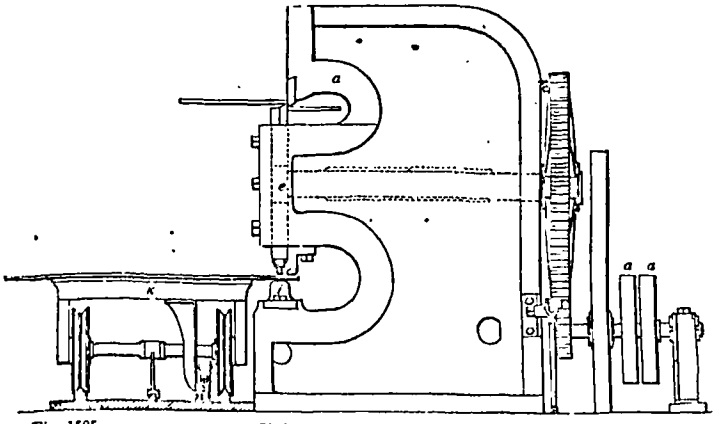


Fig. 1585. PUNCHING BOILER PLATES.

Punching Holes in plates of wrought-iron and copper: in experiments made with a cast-iron lever 11 feet in length, when the strain was multiplied ten times by means of a screw and counterpoise, the following results took place:—

The sheets to be punched having been placed between two perforated steel plates, the punch was introduced with a perfectly flat face, and then forced by the pressure of the lever. The punch was ½ inch in diameter, and through plates of iron ·08 of an inch in thickness, it required a power of 6025 pounds; through one of ·17 inches in thickness,

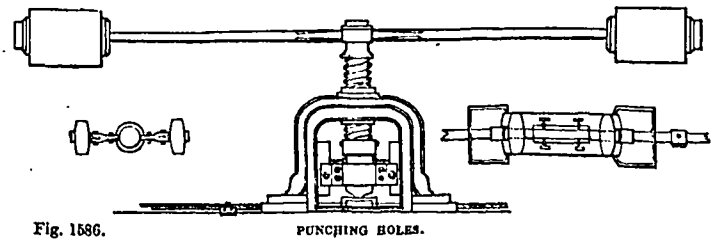


Fig. 1586. PUNCHING HOLES.

11,950 pounds; and another of ·24 inches in thickness 17,100 pounds: through a copper plate ·08 inches in thickness 3983 pounds, and ·17 inches in thickness 7883 pounds.

The power required to punch holes of different diameters through metals of various thickness is directly as the diameter of the holes and the thickness of the metal.

A plate 1 inch in thickness and having holes an inch in diameter being taken as unit for a calculation, we shall have 150,000 as the constant number for wrought-iron plates, and 96,000 for those of copper. These constant numbers being multiplied by the given diameter in inches, and then by the thickness in inches, the product will give the pressure in pounds, which is required to punch the hole.

Riveting Machines now perform the work which usually required three men, the holder on, or the one who placed the hammer against the head of the rivet, and two others, who beat out the iron to the conical form given to its opposite end: the noise which accompanied this operation is now entirely prevented. The motion is given to the machine by a leather strap, which communicates with both a tight and loose rigger; the speed is prevented from being too rapid by a pinion and large spur-wheel; as the pinion makes six revolutions, that on which the large wheel is hung, and also the cam, revolve but once.

The riveting lever rises and falls by the action of the cam, the face of which is steeled: at the lower end of the lever is a steel roller, which is turned as often as the cam works against it: this materially obviates the friction, which would otherwise be very considerable. The riveting lever moves on a fulcrum, and is connected to the riveting tool by two short links; this is kept at its work in a true and horizontal position by sliding backwards and forwards in a socket bearing.

The riveting block, in the form of a frustum of a cone, is placed on the sole plate, which receives the side framing: when the work is performed, the rivet is placed in the hole prepared for it by the punching machine: the machine is then put in motion by

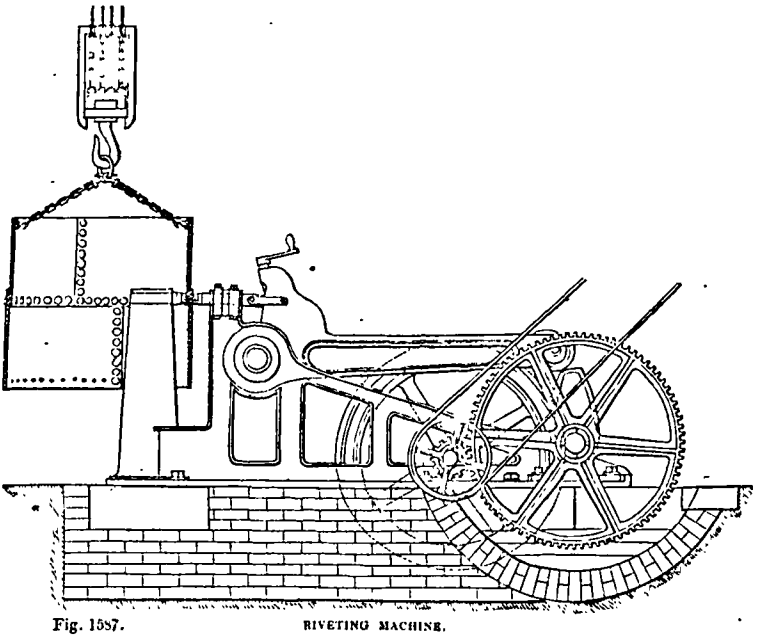


Fig. 1587. RIVETING MACHINE.

changing the position of the strap from the loose to the fixed pulley, which being communicated to the riveting tool gives the required shape to the rivet.

Eight rivets, ¾ inch in diameter, can be firmly fixed by this machine in a minute, by the assistance only of two men and two boys. In the common process, three men and a boy were required to rivet up forty in an hour; there is consequently a saving of more than 10 per cent. in the labour.

A very ingenious machine was made use of for boring the eyes of the main chain links of the Menai bridge; the side elevation and plan sufficiently indicate its form; the large

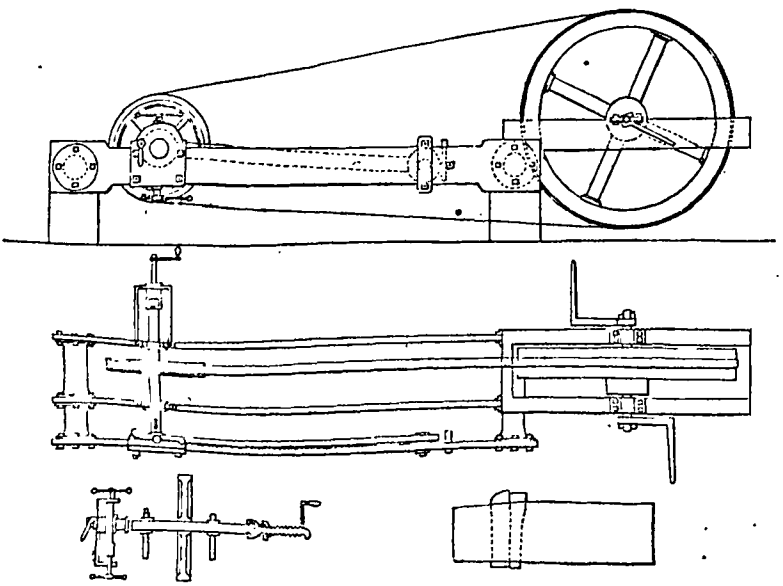


Fig. 1588. BORING EYES OF MAIN CHAINS, MENAI.

wheel was 5 feet 8 inches in diameter, and the small one 2 feet 8 inches: the transverse part of the machine is shown below, as is the end of the spindle and cutter: the whole was put in motion by means of two winches or handles and an endless chain.

Shears for cutting Iron or Copper either into square plates or lengths are formed in a similar manner to those for punching the metals, except that the motion given to the cutting part of the shears acts very gradually, by means of a circular eccentric. The lever has a wheel at its extremity, which moves on its axle: on the edge is a groove in which the

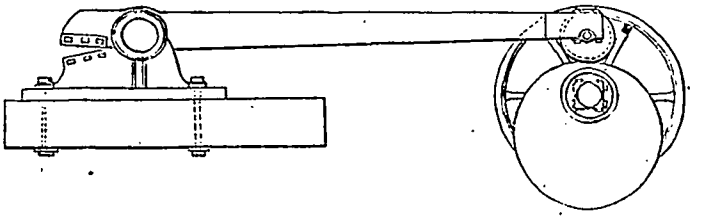


Fig. 1589. SHEARS FOR CUTTING IRON.

edge of a larger wheel works, which has the axle out of the centre; so that when the rotary motion is communicated, the movable branch of the shears opens and shuts, the weight of the lever keeping the small wheel at all times in contact with the eccentric; by this means very stout iron bars are easily cut asunder.

Slotting or key-grooving Machine somewhat resembles one made use of by Messrs. Boulton and Watt at Soho for cutting the teeth of wheels.

Slotting, paring, and key-grooving, require that the machine should have an alternate or reciprocating motion, which is usually produced by a crank or dog wheel. The machine *a* is made usually of iron, and the power applied to the driving riggers *b*, which are regulated by a fly-wheel *c*; and the speed is governed or changed by the action of a spur-wheel and pinion. The tool fixed at *i* is kept steady by screws at *h*, in the sliding frame, and the work to be operated upon is placed in the slide *k*.

There is a self-acting apparatus, by which the work is advanced at *m*, and a revolving table for circular work at *l*.

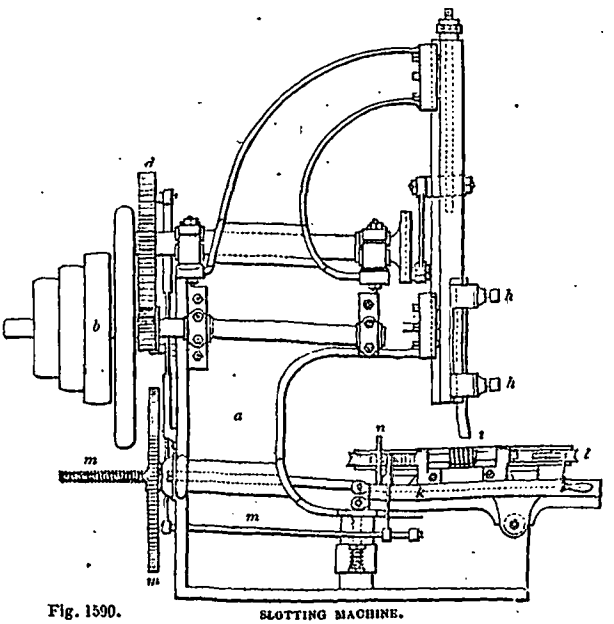


Fig. 1590. SLOTTING MACHINE.

Screw-cutting Machine is formed upon the principle of the lathe, its bed and puppets being made of cast-iron; at one end two bevelled wheels fit on a part of an axle, which may be thrown in or out of gear by means of another bevelled wheel at the side, which is put in motion either by the power of a steam-engine or water-wheel.

The screw to be cut is shown in the middle of the machine; the slide-rests, which contain the cutters of the threads, are moved forwards by the motion of the conical wheels at the end; as these slide-rests pass from one end of the frame to the other, they enable the cutter in its progress to form the thread in the revolving cylinder: when the frame has arrived at the end of the bed, it presses against a stud, to which is attached a small lever that throws the wheel out of gear; the cutting tool is again placed at the commencing end by the workman, its motion is reversed, the tool is re-adjusted, a deeper cut is made, and this is continued until the whole operation is performed.

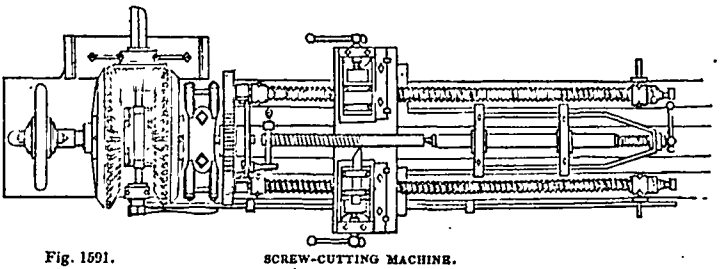


Fig. 1591. SCREW-CUTTING MACHINE.

To cut a screw with a double thread, one is first cut, the driver is then applied to a hole in an iron chuck, directly opposite its first position, by which a semi-rotation is given to the new screw, without producing a motion in the cutting frame, the cutter being applied to a point midway between two of the first formed threads: a third thread, or any number,

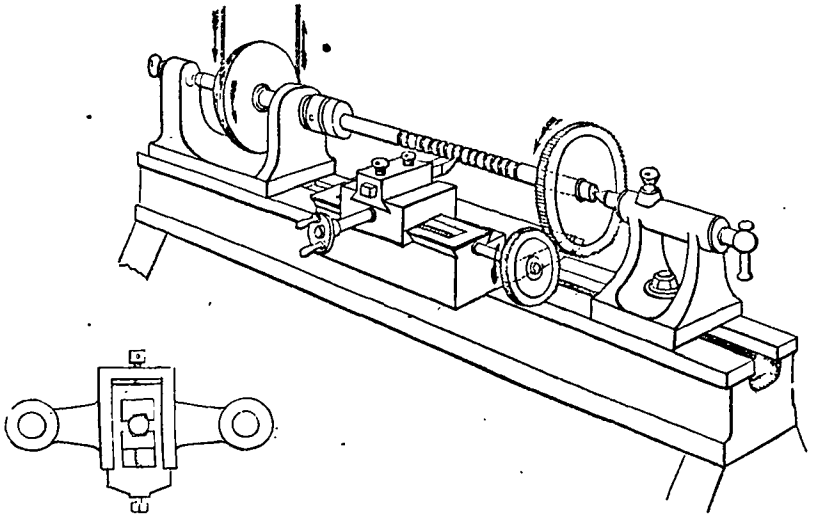


Fig. 1592. SCREW-CUTTING.

may be cut in the same manner by this machine, by commencing at a third or two-thirds or any other distance from the original position. The cutter is secured in its place by plates fastened by nuts and screws.

Another process is generally adopted for large screws, which consists of moving the slide-rest that contains the cutters, in the same way as performed by the lathe; the tool holder

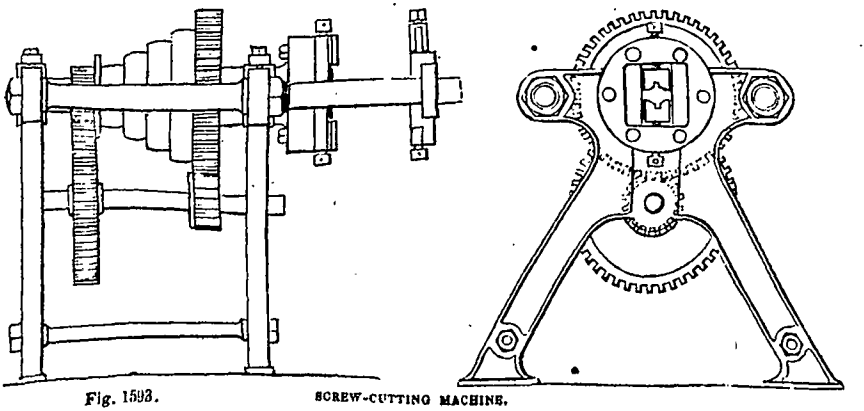


Fig. 1593. SCREW-CUTTING MACHINE.

is moved onwards by the screw, as the cylinder to be cut revolves from the motion conveyed to it by the action of the lathe; this revolving motion also affects the small screws in the rest, which yields to the point of the tool on sliding along a spiral action, which is regulated by the proportion given to the diameters of the two cogged wheels; when the diameter of that on the screw is twice that which acts in the slide, the pitch of the thread will be double or twice that of the slide screw.

Cutting the Teeth of Wheels is a similar operation: the wheel to be cut is fixed on a spindle, which forms a portion of the dividing wheel at the end, by fitting into a socket or chuck, so that when this wheel is moved round, according to the required divisions made on its face,

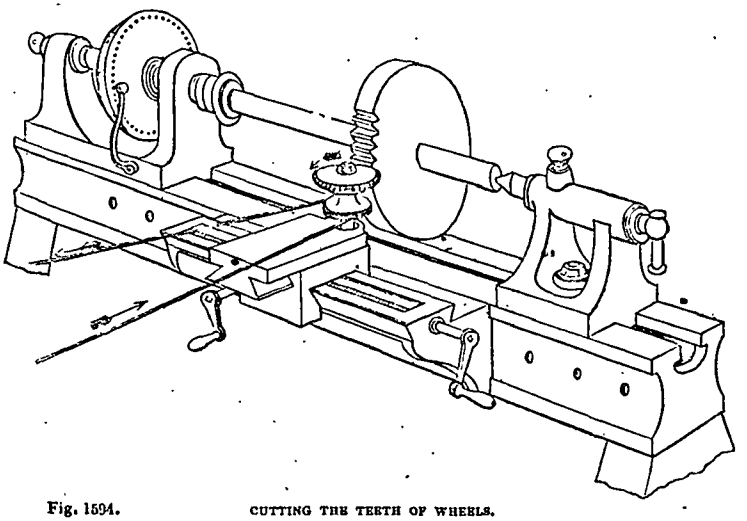


Fig. 1594. CUTTING THE TEETH OF WHEELS.

that to be cut presents its edge at the same time; the slide-rest, furnished with a revolving cutter, works at right angles against the edge of the wheel on which the teeth are to be cut, and the whole is speedily completed with great exactness. The dividing wheel is held fast as each successive tooth is formed by an iron holder, which is removed to a fresh point every time the cutter has perfected its work.

Planing Machine, here shown, has a strong vertical iron spindle, carrying the horizontal wheel, in the rim or circumference of which thirty holes are pierced, into which are introduced twenty-eight gouges or cutters and two planes; this perfectly level wheel, being well braced by the aid of the machinery at top, revolves ninety times in a minute. The timber

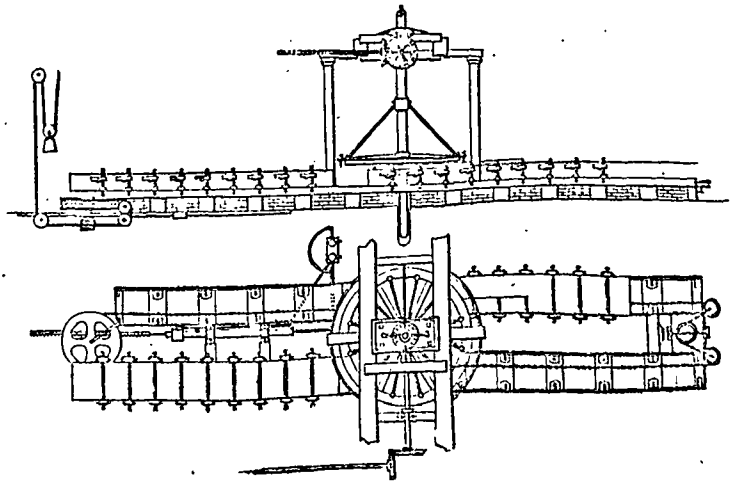


Fig. 1595. PLANING MACHINE.

to be planed is placed upon a movable frame, which regularly brings it under the action of the horizontal wheel, where the gouges and planes attached to it catch the surface in its passage, and render it at one operation not only plane but perfectly smooth.

A similar machine was contrived at the Royal Arsenal at Woolwich, and the carriages were moved backwards and forwards under the cutters by hydraulic pressure.

Machines for planing or smoothing Iron are of the greatest utility; the planing tool is fixed in a frame in such a manner that it can be inclined, if necessary, to any angle; the frame has a motion which allows it to rise up at the end of every stroke, and enables the carriage which bears the iron to be planed to pass back free to the cutter: a single workman can thus adjust the cutter at every stroke.

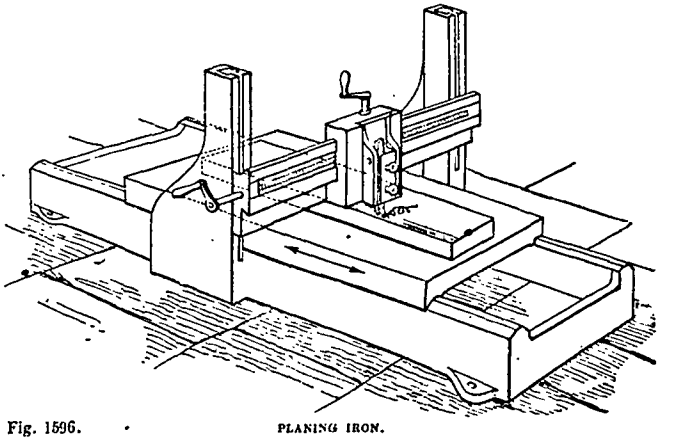


Fig. 1596. PLANING IRON.

The machine generally consists of two parts, the bed on which the table slides backwards and forwards, and a slide-rest made fast by two upright standards. The tool is held by a transverse slide, and can be lowered and adjusted to cut what is required, by turning a screw by a handle placed at the top; the whole slide traverses to any part of the width of the plate by another handle that turns the screw, which passes from one standard to the other.

There are many other applications of the slide-rest to machines and tools, and it has been found of the greatest use in all our manufactories of machinery: since iron has been so generally introduced for the construction of machines, it has been found necessary to obtain a more perfect metallic surface on it than could be performed by chipping it with a cold chisel and filing it; a process requiring also more time than could be allowed when the demand became great. The first substitutes for manual labour in smoothing iron were revolving cutters, the plate of iron to be worked off by the aid of machinery being slowly advanced under them by the ordinary rectilineal motion; in some instances the cutter or plane passed over the iron, and in others the plane was fixed whilst the iron was placed below, a method now generally adopted.

The planing tool is ordinarily fixed in a frame of iron, and can be advanced either vertically or laterally to its work; it may also be inclined in any required position, as it can

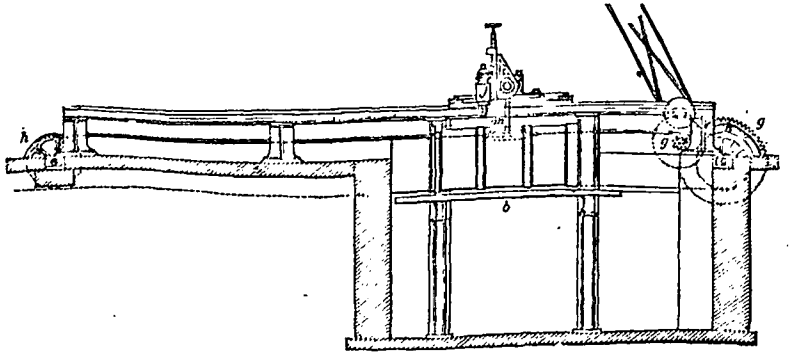


Fig. 1597. PLANING MACHINE.

be graduated to work at any angle or bevel. A motion is given to the frame which holds the cutter, by which, at the end of every stroke, it rises, to allow the carriage on which the iron to be planed rests, to pass back free to the cutter, which a workman adjusts after every stroke. The ease with which shaving after shaving is taken from the iron renders this invention one of the greatest practical utility: in many manufactories there are now planing machines which can at once smooth down a surface upwards of 15 feet in length with a face of 10 inches, and for this purpose the chisel and the file are laid aside.

Most of these machines originated from improvements made by Mr. J. Bramah, who in 1802 obtained a patent for the purpose of producing straight, smooth, and parallel, curvilinear surfaces, in a more expeditious manner than could be performed by axes, saws, planes, or other cutting instruments used by hand.

The planing tool in some of the later machines is fixed at *j*; *b* is the cylinder or work to be faced or planed; motion is given to the drum *h* by the spur-gear *g g*; *i* is a hollow cylindrical frame, on which the slide works, and by means of levers shown at *m*, the planing tool is made to come in contact with the work it has to perform.

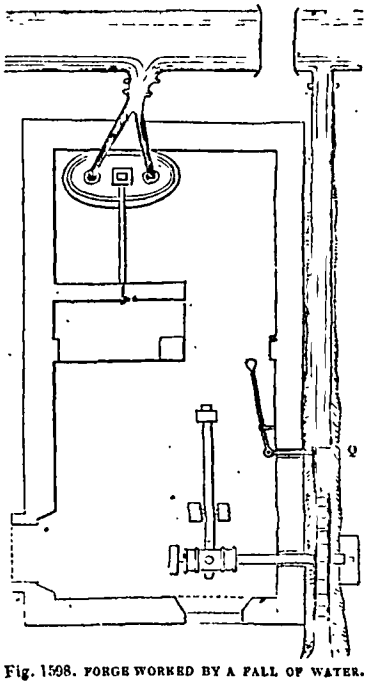


Fig. 1598. FORGE WORKED BY A FALL OF WATER.

Forge Bellows, formerly much used on the continent, consisted of two pipes, which conducted water from a stream about 10 or 15 feet in height, into others placed vertically over a tub which was sunk in the basement of the building where the blast was to be conveyed: over the middle of the top of the tub was raised a small pyramid, having at its summit a pipe through which the blast passed to the forge at A; the power was obtained by the water falling from a height sufficient to compress the air within the small pyramid, and causing it to mount and force its way out at the mouth of the pipe; this may be considered an application of the hydrostatic press for the purpose of obtaining a blast; the plan represents a forge on the Isere, between Ramand and Grenoble. The blower consists of a tub, *h i*, of an oval form, 7 feet long, and 3 or 4 feet wide. The edges are let into the ground 5 or 6 inches to prevent the air from entering; to the top of this cistern or tub two wooden pipes B, C, 10 or 12 feet high, are attached. In the middle, between these, is a kind of pyramid, G, having a tube D at the top, which conducts the air to the forge. A small trough, 1 foot wide and 7 or 8 inches deep, divided into two branches E, F, conducts the water into the pipes B, C in a greater or less quantity, according as we wish to increase or diminish the quantity of wind, by means of a sluice in the trough. As the pipes B, C have several holes near their summit inclined inwards, by which air is admitted, the water in

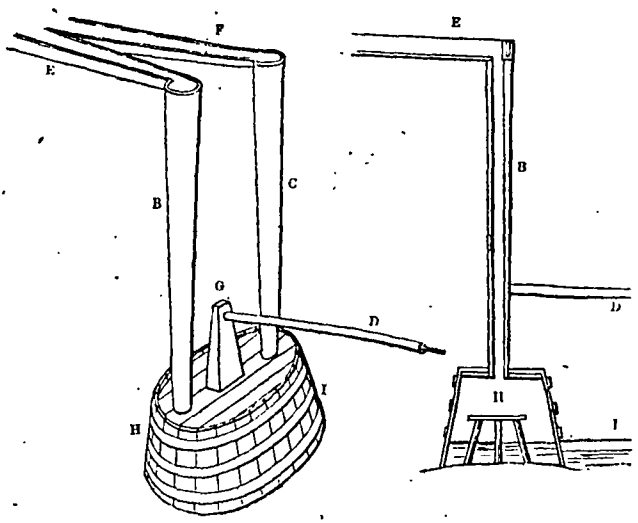


Fig. 1599. FORGE BELLOWS.

falling draws it down, and being compressed in the tub, without any other means of escape, it rushes with violence through the pipe D: within the tub is a small stool H, on which the air falling, more easily escapes from the water, which runs away by a trough, always kept full, so that the air may not issue with it. A wheel driven by a stream is shown at K Q on the plan: the hammer weighs about 300 lbs., and is stopped or set in motion by means of a sluice at Q.

Forge Hammers are still used at many of the iron-works on the continent, which receive their motion from a water-wheel, as shown at the side of the preceding figure, and at Lanslebourg in Savoy, in a manufactory of iron hoes, the forge is blown by means of water descending through two pipes into a trunk, as described above.

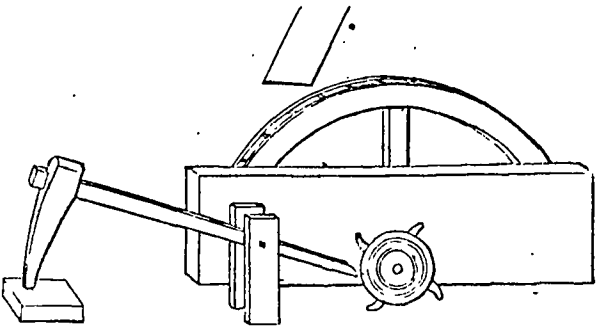


Fig. 1600. FORGE HAMMER.

The wipers which lift the cogs or cams of these forge hammers have their acting forces on the involutes of a circle, whose radius is that of the wheel, upon which they are fixed, and they elevate the hammer by acting upon a surface perpendicular to the vertical direction in which it rises, and a uniform motion is obtained.

Block Machinery at Portsmouth, put up by Mr. Maudslay in 1802, after designs of Mr. Mark Isambard Brunel, commenced working in 1804. This very complete and perfect system of machinery for the manufacture of every part of ship blocks consists of 44 separate machines, which operate upon 200 varieties required for the tackling of the navy, together forming the finest example of practical machinery in the world: the 44 machines consist of 21 varieties, which form three sets of blocks of different sizes at one time. The building that contains them has a steam-engine of 32 horse-power in the middle; it is connected on one side with seven large machines for sawing the timber into the proper sizes for the blocks, and on the other with the thirty-seven block-making machines.

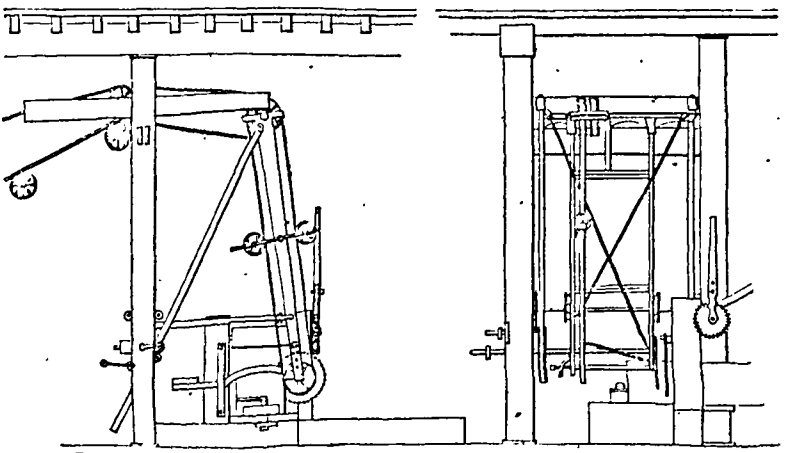


Fig. 1601. SAW MILL OF THE PORTSMOUTH BLOCK MACHINERY.

The tree is first brought to the straight-cross cutting saw; secondly, submitted to the circular-cross cutting saw; thirdly, to the reciprocating ripping saw, which cuts the elm in the direction of the grain of the wood, and afterwards in a contrary direction; fourthly, to the circular ripping saw, and the several parallelopipedons into which the timber has been sawn are then taken, fifthly, to the boring machines, where they are fixed in a frame, and two centre bits are applied; one bores a hole for the centre pin, and the other, perpen-

dicular to this, makes another, which is the commencement of the mortice to contain the sheave. The sixth machine is for mortising, and the cavities for the reception of the sheaves are formed by chisels in two blocks at the same time. In the seventh, a corner saw cuts off the angles of the blocks. The eighth is the shaping machine, which consists of a double wheel, and contains the ten blocks at one time; when these are put in motion, the external faces of the blocks pass under the gouges, which cut them into the form required.

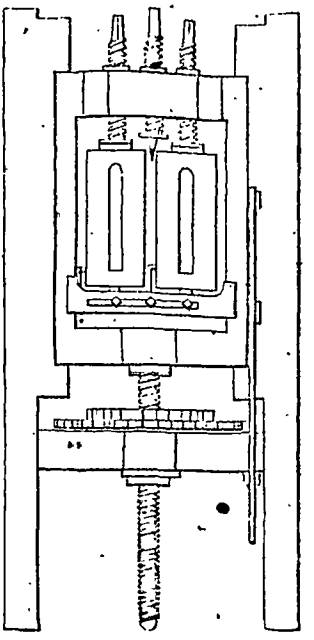


Fig. 1602. BLOCK-MAKING MACHINE.

The plan of the machine shows the two wheels fitted on a common axis, which together form a chuck; the blocks are retained by the screws; the compound wheels or chuck, as it has been termed, receive a rapid circular motion from an endless rope, which passes over the pulley on the axis; and the blocks can be operated upon in any way required, by presenting the gouge or cutting-tool, which traverses a segmental bar by means of a slide rest. The workmen guide the cutting instrument to any part of the surface, as it revolves by handles, and thus cut it into shape: after the edges of the blocks have been taken off, the machine is stopped, and they are turned round one quarter on their respective axes, presenting another side as the wheels revolve, and, in a similar way, they are again and again turned until they receive their complete form. The large bevelled wheel next the pulley wheel turns two other bevelled cog-wheels fixed on a rod, at the end of which is an endless screw, with the axis tending to the centre of the chuck. On the large wheel is a pin projecting from its circumference, which is detained by means of a stop that occasionally presses the pin, and turns the chuck round on a fork, which stops the motion of the wheel; it is then that the attendant workman, by means of the endless screws, places the blocks in a proper position to be cut by the gouge.

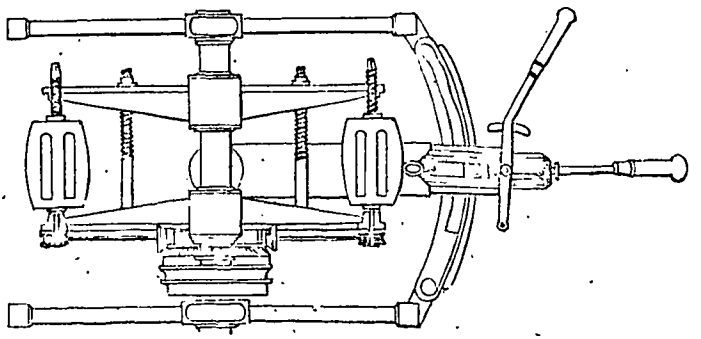


Fig. 1603. BLOCK-SHAPING MACHINE.

The ninth is the scoring engine, for cutting the groove round the largest diameter for the reception of the strap of the block; thus the shells of the blocks are prepared, after which they are trimmed, polished, and finished by hand.

The machines for making the sheaves are the next, and the tenth is the straight saw, employed to cut the lignum vitæ.

The eleventh is a circular saw, employed when smaller sheaves are required.

The twelfth is the crown saw, which works similarly to a trepan, having a centre bit on its axis: it is used for cutting out the circle, and at the same time the hole in the centre.

The thirteenth is the *coaking* engine, which cuts the cavity in the centre of the sheave for the reception of the *coak* or metal bush.

The fourteenth is the drilling machine, which is applied to perforate the three semicircular projections of the coaks, at the same time drilling through both the coaks and the wood of the sheave.

The fifteenth are the hammers, put in rapid motion by the machinery, for riveting the pins which hold the gun metal coaks into the cavity in the sheaves.

The sixteenth is the broaching engine, where the sheave is fixed to a vertical revolving axis, and the borer is brought down into the hole in the centre of the coaked sheave, and broached out to a perfect cylinder.

The seventeenth is the turning lathe, provided with a slide rest to support the turning tool, by which the sheaves are faced. Thus the blocks, shells, and sheaves are completed.

The eighteenth is a turning lathe, with a slide rest to form the iron pins.

The nineteenth is a polishing engine, in which the pin is fixed into the lower end of a vertical revolving axis, and forced down into a die immersed in oil, holding three pieces of hard steel, between which the pin is pressed as it turns, and becomes completely polished.

The twentieth apparatus is for boring large holes in any position, and is mostly used for blocks that are 50 inches or more in length, and have four sheaves.

The twenty-first is the machine for making dead eyes.

By this machinery 1420 blocks are perfected in one day, and it is not too much to observe that the entire contrivances seem to embrace all the useful purposes that are required throughout the entire range of the mechanical arts. In the Edinburgh Encyclopædia, conducted by Dr. David Brewster, are most perfect and beautiful representations of these machines.

Saw Mills for cutting Marble: the frame is suspended by rods, in such a manner that a free horizontal reciprocating motion is given to it; the saw frame is attached to a cast-iron

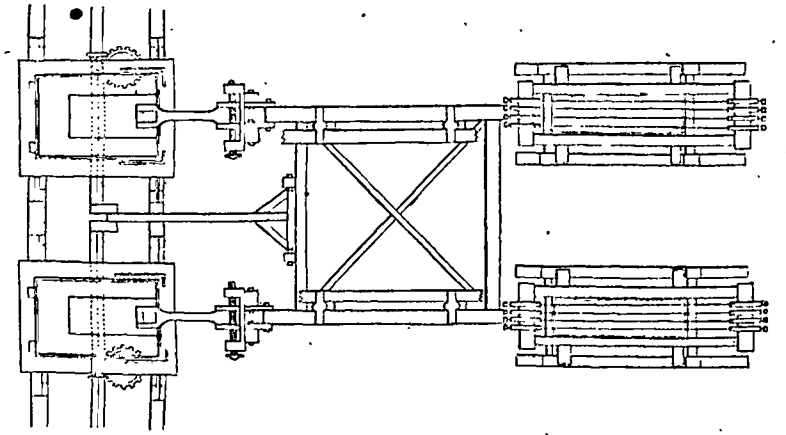


Fig. 1604. PLAN OF MARBLE SAW MILL.

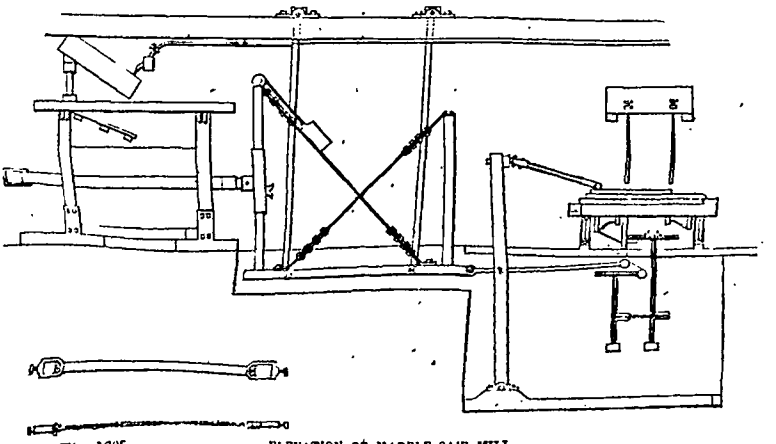


Fig. 1605. ELEVATION OF MARBLE SAW MILL.

box, which is movable upon a vertical post, from whence it receives its reciprocating motion: it is made of wood, and the saws are tightened within it by several screws: any number of saws may be introduced, and at any distance apart, according to the number of slabs or thicknesses to be cut: on the left of the plan are shown two sets of saws at work, with four blades in each set. The saws are guided by upright iron bars, which also maintain them in a vertical position, and they are pressed upon their work by a cast-iron box, suspended by a rope that passes over a pulley, and slides down upon the upright post of the vibrating frame; a weight is attached to the other end of the rope, as shown in the section. Water is introduced by a horizontal pipe under the ceiling of the manufactory, and runs gently into the small inclined reservoir immediately above the block, which is under the action of the saws: after the slabs have been cut, they are carried to the other side of the machine, where they are laid flat and polished. The polisher is put in motion by the action of the vertical post, which receives its vibration from the saw-frame by the crank upon the main shaft: a continued supply of water is introduced with the various substances made use of for polishing: sharp sand is first supplied, which produces a perfectly flat surface, then finer sand, and afterwards Tripoli red powder, which owes its cutting quality to the oxide of iron that it contains; an oxide of tin, called putty, completes the polish.

Hand-mills, for grinding, are of very great antiquity, and had a variety of forms; one of the most simple kind consists of a strong wooden frame, on which is mounted a face-wheel, turned on proper bearings by a winch or handle, and which has its cogs engaged in the staves of a trundle or lantern, on the spindle of which the revolving stone of the mill, contained in the case below, is fixed. The matter to be ground is put into the hopper at the side, from whence it passes to the space betwixt the fixed and revolving stone, after which it is carried away, by means of the lower spout or trough, into a vessel prepared to receive it: such mills are much used for numerous purposes, and are an improvement upon the Roman hand-mill, which was an inverted hollow cone, working round and upon a solid one below: when the stones are laid horizontally, there is an equal bearing and friction over the whole.

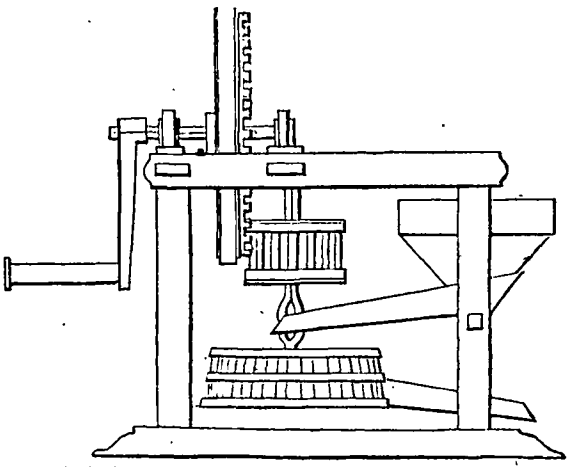


Fig. 1606. HAND MILL.

Horse-mills are frequently used in manufactories in preference to the steam-engine, and they are serviceable and convenient where the labour required is not constant. The speed

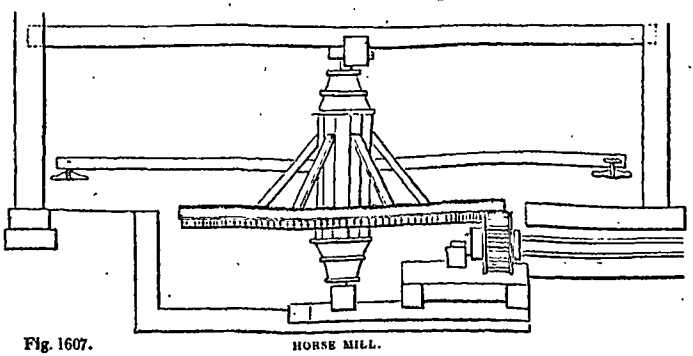


Fig. 1607. HORSE MILL.

with which a horse moves, so as to produce the maximum mechanical effect, is stated to be two and a half miles per hour, or 220 feet per minute, or 3⅔ feet per second; and the actual

medium effect of a horse will raise each minute 22,000 pounds a foot high, although horse power is defined to be competent to raise 33,000 pounds in the same time; but when employed in mills the action of the animal is perpetually restrained by the circular path in which he walks, and the power is not so great as when pulling in a direct line; and in some

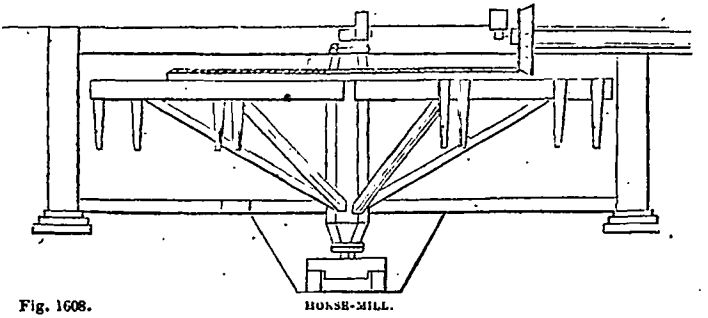


Fig. 1608. HORSE-MILL.

measure to alleviate this impediment, it is an invariable rule never to make the diameter of the horse-path less than 18 feet in diameter. Rotation is given to such mills either by large cogged or bevelled wheels placed below or above the revolving shaft; the horses in the one case walking on a level with the large cogged wheel.

If a steam-engine of 10 horse nominal power taken at 33,000 lbs. were to work day and night, it would perform as much as 45 horses in the same time; and making every allowance for casual and necessary stoppages, every nominal horse power in a steam-engine is equivalent to four horses when working night and day, to two horses when working twelve hours a-day, and to one and a half horses when working eight hours a day.

Mills for grinding Corn by the power of steam, were first used in 1783, on the Surrey side of Blackfriars bridge, but in consequence of their being considered a monopoly injurious to the public, they were destroyed by fire a few years afterwards.

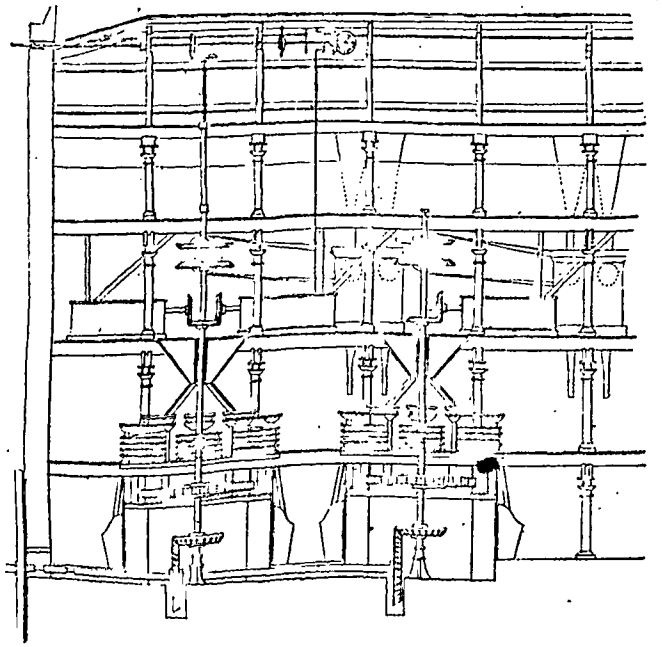


Fig. 1609. CORN MILL.

Since that period, Messrs. George and John Rennie have erected at the Royal William victualling yard, Plymouth, one of the most perfect mills in the kingdom for grinding corn. The building is 240 feet in length, and 70 feet in height: in the centre are two steam-engines of forty-five horse power; on each side are twelve pair of stones 4 feet 3 inches in

diameter, each performing 123 revolutions in a minute, and grinding five bushels of corn per hour, so that when the mill is in full work 120 bushels of corn are ground in that time, as well as dressed by eight machines.

The fly-wheel that communicates the motion is on the left of the figure; the main shaft has its bearings in plummer blocks bolted to cast-iron frames; on it are two bevelled wheels 8 feet in diameter, which engage two others, 5 feet 4 inches in diameter, placed on the main vertical shafts, which have their bearing at the lower end, on another cast-iron frame, and on brasses and other plummer blocks attached to the floor of the mill. The shafts are all placed in a well or circular mass of bulwark, and the large cog-wheels above, 10 feet in diameter, turn six toothed wheels set round their circumference, upon the spindles of which the upper millstone is fixed, and revolves very rapidly.

The corn is laid on the upper floor, and then by spouts conducted first to screening machines or cylindrical sieves, arranged somewhat like an Archimedean screw; it is admitted at one end, and in its course passes over a larger surface of wire; when cleaned of the sand and dust, it falls into a hopper, from which it passes by spouts to the millstones.

On the second floor of the mill the dressing machine and bolting mills are arranged, which are put in motion by a bevelled wheel on an horizontal shaft, which can be put in or out of gear with the vertical shaft at pleasure. The machinery for raising the sacks is suspended on the beams of the roof; it consists of a barrel and a system of wheel-work put in motion by a bevelled wheel on the top of the vertical shaft.

The millstones are composed of a number of pieces attached together by a strong cement, and further secured by iron hoops passing round their circumference: on the

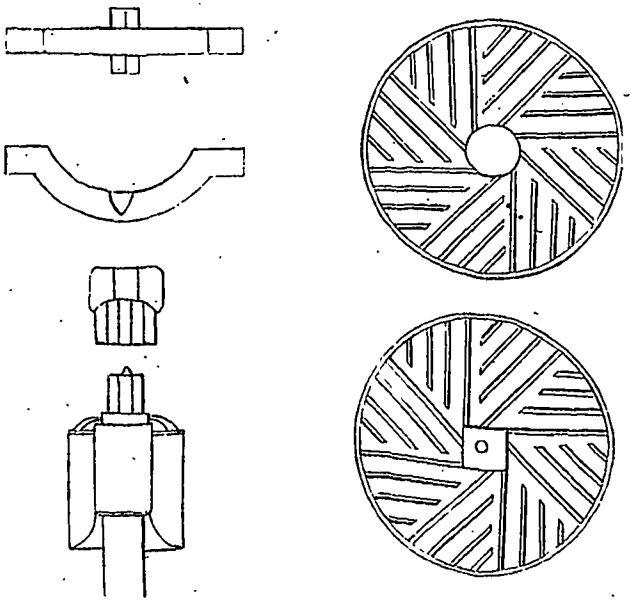


Fig. 1610. MILLSTONES.

upper and lower millstones are grooves or channels cut obliquely from the circumference, to within an inch and a half of the centres: eight long channels divide the stone into as many portions, in each of which four others are usually cut; these furrows are sunk in such a manner that one side is perpendicular, and the other oblique, and one being placed upon the other, the sharp edges meet, and effectually cut the corn, which passes between them. In bedding millstone, great care must be taken to have them perfectly level, and firm on their bearing; they are sometimes supported by a timber frame, which is wedged up from the floor, but more frequently an adjustment is effected with an iron frame and screws.

The bed stone in the figure is fixed in an iron case, which can be raised or lowered by turning the iron screws beneath, and at the side are other screws which move the stone laterally when required: when the iron cross or damsel above revolves, it strikes the shoe under the hopper, and gives it a tremulous motion, which causes the wheat to pass down from it to the millstones, in proportion to the velocity of the motion. The upper mill-

stone is fixed upon the shaft by means of a cross with a segmental top, which is firmly attached to it, and the octangular axle passes through the iron box on which this upper stone hangs

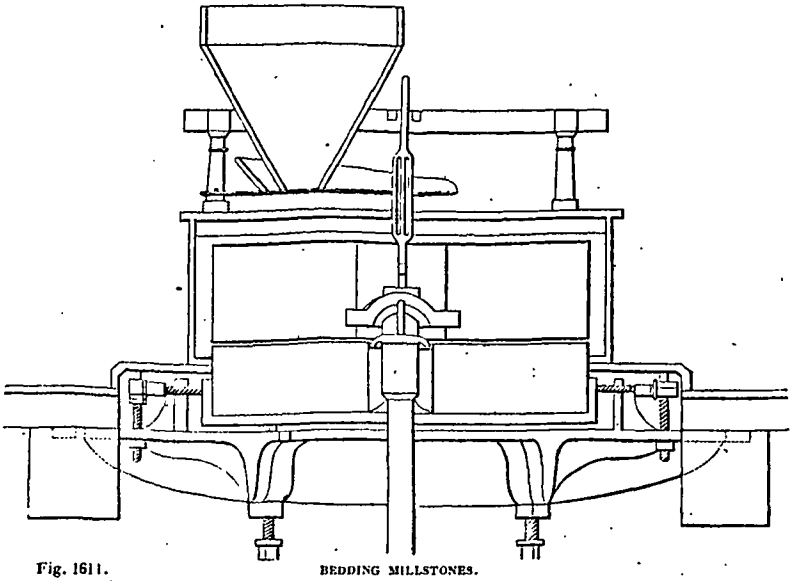


Fig. 1611. BEDDING MILLSTONES.

In the Victualling Yard at Deptford, the millstones, which are not quite 4 feet in diameter, make 120 revolutions in a minute, and answer admirably well; though they generally vary from 4 feet 6 inches to 5 feet in diameter, and make from 80 to 100 revolutions in a minute.

The Dressing Machine is a hollow cylinder or frame, covered with wire cloth of different degrees of fineness, that is, with 64, 60, 38, and 16 meshes to the inch, that which has the smallest space being at the upper end: its axle is inclined to the same angle as the bolting mill. Within the cylinder, which is stationary, is a reel, to the rails of which are attached brushes, which, in their revolution, act against the interior wire surface of the cylinder; the meal is conducted within it by a spout or hopper, and is thus rubbed through the wire, the finest passing through the upper end, the second through the next division,

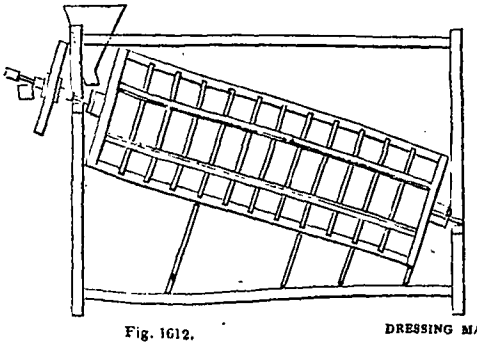


Fig. 1612.

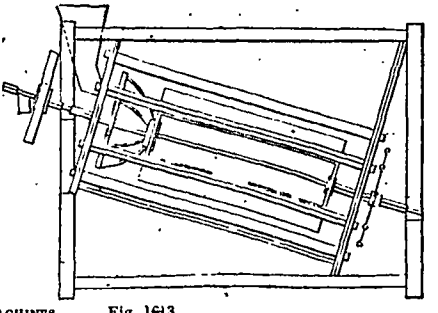


Fig. 1613. DRESSING MACHINES.

and the bran through the lower end: the cylinder being enclosed in a tight case, the flour cannot escape; there are usually four divisions within it, to collect the varieties of flour as they are rubbed through: hence they are called, firsts, seconds, thirds, and pollard. The pinion upon which the brushes move can be made to revolve either way, so that the motion of the machine can be reversed to suit the brushes, when they become bent in one position.

The Bolting Mill consists of a reel fitted to an axle which revolves with great rapidity, and is covered with a cloth called duck: in the box containing the reel are a number of wooden bars called beaters, against which the cloth strikes with such violence that the flour is separated from the coarser parts or pollard.

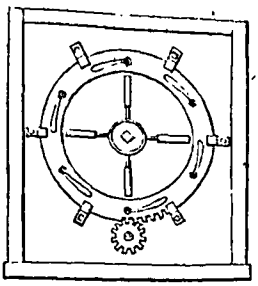


Fig. 1614.

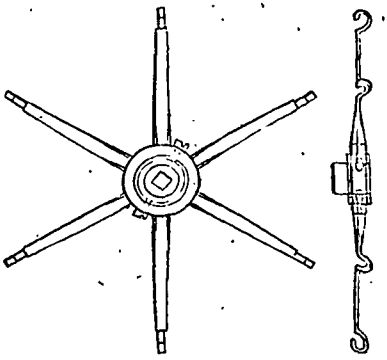


Fig. 1615.

The reel has six bars fixed in an axle which works in a circle, and at the upper end is 22½ inches in diameter, and diminishes gradually to 20½ inches at the lower or tail end: when at work it is turned with sufficient velocity to make the bolting cloth swell out to its fullest extent, and occasion the beaters to force the flour through the meshes of the cloth in a constant stream.

Some bolting machines have a contrivance applied to them containing a spring, which facilitates the dressing of the flour: it consists of a cylindrical ring of iron, into which are riveted six elastic arms: at the end of each is a hook, to receive a loop attached to the tail leather of the bolting cloth, causing a more uniform action to be kept up.

The Mortar Mill is composed of a vertical shaft or spindle, to which the millstone is attached, revolving on a bed upon which the limestone or chalk to be pounded is thrown: curved pieces of iron, called rakes, are fixed to the shaft, and revolve round in a regular manner to keep the iron bed free from any impediment to its regular motion: when the lime is properly ground, it is passed into another mill, where it is mixed with its proportion of sand, and triturated or compounded by the action of constantly revolving

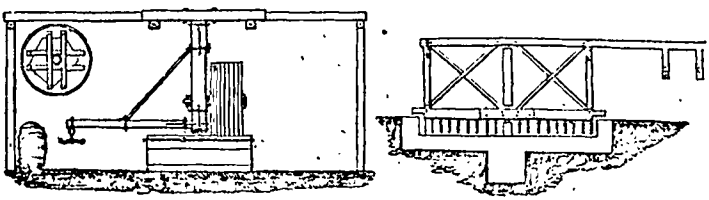


Fig. 1616. MILL FOR MIXING MORTAR.

rakes, attached to the arms of a horizontal wheel that moves round in a circular bed. The pug mills are upon a similar construction, and have a post in the middle with a long lever, to which the horse is applied The lime and sand thrown into the trough are then mixed by the revolving rake fixed at the lower part of the upright shaft.

Mills for grinding Cement are formed like the corn mill, with the addition of two iron rollers, shown under the right hand hopper, which receive motion from a spur-wheel attached on the main shaft: by means of the rollers the cement stone is first broken down into a powder or small fragments, after which it is hoisted to the top of the mill in sacks, and then put into the hopper, whence it passes off to the millstones; the lower one being fixed, and the upper put in motion by the machinery.

The millstones are grooved or channelled obliquely, from the circumference, as in the flour mill, and make about 150 revolutions in a minute: when the cement is ground, it passes out at the circumference of the stones into a spout, which conveys it to two sieves, separating the fine powder from the coarse: the sieves placed beneath the large horizontal wheel have a rapid reciprocating motion by a rod and crank attached to the small spur-wheel, which is turned by the larger wheel just mentioned.

To the right of the figure is a mortar mill, which works by means of the spur wheel, and into which the cement powder is put, when prepared for use. At Sheerness dock-yard a twelve horse-power steam engine was made use of to work a similar cement mill.

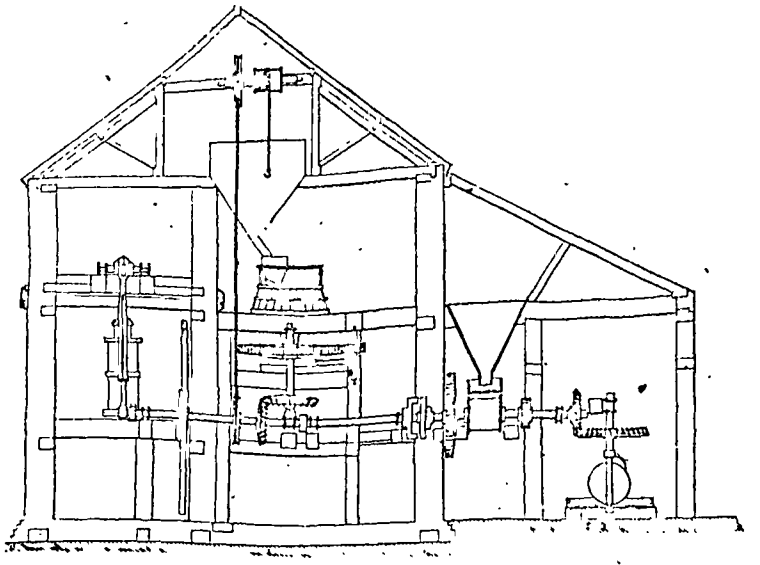


Fig. 1617. CEMENT MILL.

Diving Bell. — The earliest account we have of a machine similar to that now in use is given by John Taisner, of Hainault, who was born in 1509, and went to Toledo with the Emperor Charles V.: "he there saw two Greeks let themselves down under water, in a large inverted cauldron, with a burning light, and rise to the surface again without being wet." Lorini, in a work upon fortification, also describes a diving machine, consisting of a square box bound round with iron, and furnished with windows; but no mention is made of such a machine in England until Dr. Halley commenced his experiments; that ingenious philosopher contrived means to supply the diving machine with air, and at the same time to keep the water from rising in it; his description of the apparatus in the Philosophical Transactions is as follows: —

"The bell I made use of was of wood, containing about 60 cubic feet in its concavity, and of the form of a truncated cone, whose diameter at top was 3 feet and at bottom 5 feet; this I coated with lead, so heavy that it would sink empty, and I distributed its weight about its bottom, so that it would go down in a perpendicular situation, and no other; in the top I fixed a strong but clear glass, to let in the light from above, and likewise a cock to let out the hot air that had been breathed; and below, about a yard under the bell, I placed a stage which hung by three ropes, each of which was charged with 1 cwt. to keep it steady. This machine I suspended from the mast of a ship by a spreit, which was sufficiently secured by stays to the mast-head, and was directed by braces to carry it over-board clear of the ship's side, and to bring it again within board.

"To supply air to this bell when under water, I caused a couple of barrels of about 36 gallons each to be cased with lead, so as to sink when empty, each having a bung-hole in its lowest part, to let in water as the air in them condensed on their descent, and to let it out again, when they were drawn up full of water from below, and to a hole in the uppermost part of these barrels I fixed a leathern trunk or hose, well liquored with bees'-wax and oil, and long enough to fall below the bung-hole, being kept down by a weight appended, so that the air in the upper part of the barrels could not escape, unless the lower ends of these hose were first lifted up: I fitted these air barrels with tackle proper to make them rise and fall alternately, after the manner of two buckets in a well, which was done with so much ease, that two men, with less than half their strength, could perform all the labour; and in their descent they were directed by lines fastened to the under edge of the bell, which passed through rings placed on both sides the leathern hose of each barrel, so that, sliding down by those lines, they came readily to the hand of the man who stood on the stage to receive them, and to take up the end of the hose into the bell. Through these hose, as soon as the ends of the pipes came above the surface of the water in the barrels, all the air that was included in the upper parts of them was blown with great force into the bell, whilst the water entered at the bung-holes below and filled them: as soon as the air of one barrel had been thus received, upon a signal given it was drawn up, and at the

same time the other descended, thus by alternate succession furnishing air so quick and in such plenty, that I myself have been one of five who have been together at the bottom in nine or ten fathoms water, for above an hour and a half at a time without any sort of ill consequence; and I might have continued there as long as I pleased, for any thing that appeared to the contrary. Besides, the whole cavity of the bell was kept entirely free from water, so that I sat on a bench, which was diametrically placed near the bottom, with all my clothes on; I only observed that it was necessary to be let down gradually at first, or about 12 feet at a time, and then to stop and drive out the water that entered, by receiving three or four barrels of fresh air before descending any further, but being arrived at the depth designed, I then let out as much hot air that had been breathed as each barrel would replenish with fresh air, by means of the cock at the top of the bell, through whose aperture, though very small, the air would rush with so great violence, as to make the surface of the sea boil, and cover it with a white foam, notwithstanding the great weight of water over us."

Since Dr. Halley's invention, many improvements have been made in the diving bell, particularly by Mr. Smeaton, who seems to have been the first engineer that used it for sub-marine constructions.

When the diving bell is employed in still water, it is usually suspended between two boats of 15 or 20 tons each, over the decks of which is laid a platform of timber, to keep them at the proper distance from each other, and on which the tackle is worked for lowering and raising the bell.

Smeaton employed the diving bell as early as 1778, in the constructions of the bridge at Hexham: in a letter which he addressed to Mr. Pickernell on the subject, we have the method he adopted fully explained: he says, "If the cases would have enabled us to reduce the water so low, as to be even with the very bottoms of the caissoons of each pier, I take it for granted, you would have thought it no difficulty with broken rubble, beton, stones, and short blocks of wood, cut a little wedgeways, to have crammed and wedged up the cavity washed under the wooden bottoms, so as to have been equally resisting, and capable of bearing a weight with the original gravel, and particularly when this new body of matter is supported, and even jammed tighter into its place by filling up the vacancy between the pier and the base, a little above the wooden bottom, with rubble, and then driving it tight down by a set with the ram. It therefore now remains that I describe, and make you master of a piece of machinery, that will put you nearly into the same condition, as if the water could have been reduced to the caissoon's bottoms as before mentioned; and this is by means of an air-chest, or diving vessel, which being let down, will exclude the water down to the very bottom of the diver if you please, and therefore as low as the under side of the wooden bottom, which in the present case is as low as will be necessary or useful, and the chest or vessel being large enough to give liberty for a man to work therein, being furnished with a pair of boots, he will at mid leg deep in water do his business with almost as much facility as if the water were pumped out to the same level. The principal part of this machine will consist of a strong chest, suppose 8 feet 6 inches in length, about 4½ feet deep or height, and as wide as to give free leave for its going down between the cases and the piers, which I suppose will be about 2 feet wide inside measure, as the other measures are also supposed to be. Now you know very well that if you push a drinking glass, or any other similar vessel, with its mouth downwards into the water, that it will exclude the water, leaving the vessel full of air, as it was before it was thrust into the water; in like manner, if this chest, being loaded with a sufficient weight, be let down into the water, mouth downwards, the air will exclude the water to the bottom skirt of the chest, and if let down, so as to rest upon the bottom of the river, a man may stand therein, and do any kind of business, the same as he could do in the same space in the open air. But to continue this for any length of time two things are obviously necessary, and those are light and a circulation of fresh air. The former might on occasion be supplied by a candle, but here we may have the advantage of day-light by putting two or three strong round panes of glass into the bottom of the chest, which will in its inverted situation be the top; a sufficiency of light will enter, this top of the chest being supposed above water. Respecting air, you will conceive that any quantity might be forced in by a strong pair of bellows; but those made of leather would be cumbersome and unhandy: I therefore substitute a kind of foreign air-pump, made of thin hammered copper, that will throw in a gallon at a stroke, which will not only continually refresh the workmen within, but whatever air escapes through the joints or pores of the air-chest will be replenished, and the overplus go out at the bottom or skirt of the chest, and boil up on the outside.

The quantity of weight that will sink it, mouth downwards, will be the same as placed therein (bottom downward) would sink it the same depth; and as this chest I propose to be suspended by a tackle, and to go down by its own weight, I compute that it will take sixteen pigs of lead to sink it to the bottom of the river, and keep it steady. I propose that the lead may be as much out of the way as possible, to place them upon the ends of

the chest, endways upward, that is four in a row below and four above, and the same at the other end, making in the whole 16 pigs, which are to be fastened on with screws, either by cleats screwed on, or punching a hole through each end of each pig. At one end of the chest there is to be a board, fixed across for the man to sit upon, and a cleat nailed to each side to set each of his feet upon, so that while the machine is being lowered or hoisted, he is totally dry, and when let down enough, he stands upon the bottom of the river, without any more water than the height between the skirt of the chest and the bottom of the river, which may be more or less as is found convenient, I suppose never more than a foot deep, because wherever the ground is taken out more than 1 foot below the underside of the caissoon's bottom, I would propose to fill it up with rubble previously to that height or depth; nor can it be of use to let down the skirt of the chest much below the caissoon's bottom, because the side of the chest will then diminish the room you will have to get the matter for underpinning under the caissoon's bottom. The foregoing will, I believe, be sufficient for explaining the general principles and outlines of the method I mean to pursue in underpinning, and re-supplying what is underwashed from the bases of the piers, and which I dare say you will now see to be entirely practicable: what you are therefore immediately to put in hand is the air-chest, of or about the inside dimensions before mentioned; I believe the two flat sides will do very well, if of good red wood deal, shot clean of sap, the two ends and bottom, (or in use its top); it would be well if they could be got of single planks of elm, beech, or plane trees, as they would hold the nails better: I fancy $1\frac{1}{2}$ or $1\frac{3}{4}$ inches thick for the sides, $2\frac{1}{4}$ or $2\frac{1}{2}$ for the ends and bottom, will be sufficient; they should be well jointed, and put together with white lead and oil, as the effort will not be of the water to enter, but of the air to escape from within. Were I with you, when it is put in use, I should be the first to go down into it, as there is no more danger (all your tackle being firmly fixed) than being let down into a coal-pit by a rope: and if it shall happen that all your masons are too fine fingered, I fancy a couple of colliers to take turn and turn will find it a very comfortable job. A particular encouragement, must, however, I expect be given. I will give you more particular directions in my next: as to the air-pump, all that will be wanted from the coppersmith will be a cylindrical pipe of copper; 10 inches diameter, and 12 inches high, wired at top, and a flanch at bottom of about $1\frac{1}{4}$ inches broad, by which it is screwed down before the top of the air-chest: the copper to be about the thickness of a halfpenny; if you have no neat-handed coppersmith that can hammer it straight and smooth inside, it may on occasion be made of strong tin."

"A, the air-pump, B, sky-lights, 6 inches in diameter, to be made of window glass knobs, if plate glass cannot be had; C, clamp plates of iron, to confine the top and sides strongly together; D, D, pigs of lead, end upwards; E E, the lever for working the pump; G G, the axis and brace for steadying the lever; H, H, two bows for hoisting the chest; I, a strong hooked iron to lay hold of the bows, to which the main rope or tackle is to be fixed: M N, the opening from the pump to the air-chest: *op*, the valve, whereof *o* is leather, *p* wood, to be shut by a wire spring *qrs*, a little more than sufficient to overcome the weight of the valve."

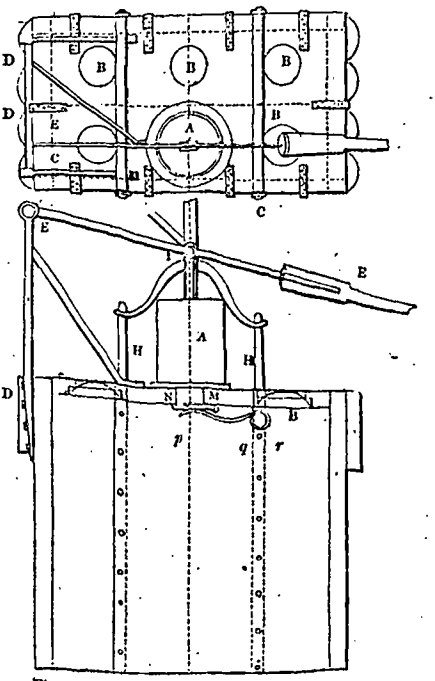


Fig. 1618. SECTION OF AIR-CHEST.

The diving bell at Her Majesty's dockyard at Plymouth is of cast-iron, and weighs 4 tons 2 cwt. It is 6 feet long, 4 feet broad, and 5 feet in height; its cubical content being 120 feet.

Twelve convex lenses, each 8 inches in diameter, are placed at the top to admit the light, which when sunk in clear water is sufficient to enable the diver to read the smallest print. In the centre of the top is a hole for the admission of air, which is supplied by a leathern hose long enough to reach any moderate depth; at its upper end is attached a forcing or air-pump, which is worked by four men during the time the bell is immersed, and the quantity of air supplied enables those in the bell to respire with

comfort. Inside the bell, and immediately over the hole, which admits the air, is screwed a piece of stout leather, so that the air only enters through the spaces comprised between the screws; this leather prevents the air, when once admitted, from returning to the hose; and should it burst, the water cannot enter through the air hole; the divers are therefore secured against any accident which might arise from this cause, and the bell contains a sufficient quantity of air to support those within it, without the assistance of the air-pump, until it could be raised up from almost any depth.

When the bell is overcharged with air, it escapes under its edge, and from its expansive nature, agitates the water as it ascends towards the surface; this has been supposed to be the foul air escaping, but that which has been respired, being lightest, ascends to the upper part of the bell, and a continued current of air passing from the top to the bottom prevents any unpleasant effect.

There is a movable seat at each end, and a narrow foot-board, with several hooks and shelves for the workmen's tools, and at the top are two eye-bolts for the purpose of securing any heavy weights which may be required to be raised with the bell.

No difficulty or danger attends its use, provided the men are sufficiently careful, and the bell is properly suspended: when immersed, and the divers require its position to be changed, they strike it with a hammer. Eight signals are made: one strike indicates that there is not sufficient air, and that it is necessary to work the pump faster: two annuls a former signal: three, that the bell is to be raised: four to lower it: five, to move it to the right; six, to the left; seven, backwards, and eight, forward: other methods are resorted to for holding a correspondence with those in the vessel, as sending up small buoys, &c.

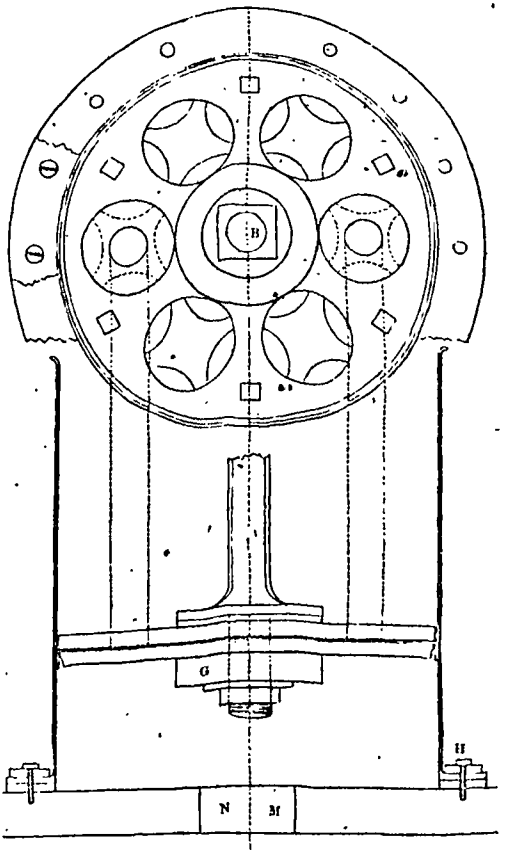


Fig. 1619. PLAN AND SECTION OF AIR-PUMP.

When any work is to be executed by the diving bell, it is important that the water should be transparent, or at least sufficiently so that objects may be discerned when lying two or three feet below the bell, that the machine may not touch them in its descent: with artificial light it is impossible to distinguish objects in muddy water; but when clear, a cloud passing over the sun is perceptible in deep water. The workmen employed usually in the summer remain from 7 to 12 o'clock in the morning, and from 1 to 6 o'clock in the evening, and in winter only as long as they can see.

It is necessary to observe that the greatest caution is required in lowering the bell: if it descend with too great velocity, the air becomes so much compressed as to be injurious to the lungs of the workmen, sometimes causing immediate death; when the descent is very gradual, no evil consequences will arise.

The diving bell at Ramsgate harbour was a square chest of iron, weighing 50 cwt.; its dimensions were 4½ feet in height and length, and 3 feet in width: it was cast in one piece, and sufficiently heavy to sink itself: by means of a forcing air-pump, worked in a boat moored immediately over the bell, two men were supplied with fresh air: in the crown were eight round lenses, 4 inches in diameter, to admit the light. It was at first suspended from shears, but Mr. Gott, the resident engineer, finding them inconvenient, adopted the traversing crane, which enabled the masons to place the stone in any position required:

another bell has been since cast, 6 feet long and 4 feet broad, which permits the workmen to proceed with greater alacrity.

The Camel is a machine used in Holland for raising ships by the buoyant power of water; it is a very ingenious contrivance, and consists of two similar hollow vessels, so constructed that they can be applied on each side of the hull of a ship; these hollow vessels are made water-tight, and on the deck of each windlasses are attached, by which ropes, which are made to pass under the keel of the vessel to be raised, are worked. When the camel is employed to raise a ship, the water is allowed to fill each half of it, and when the ropes firmly unite the ship to the camel, the water is pumped out, and the buoyancy of the hollow vessels raises the ship up.

The length of one of these camels employed to float vessels over the sands in Holland was 127 feet, the breadth at one end 22 feet, and the other 18 feet: the hollow part was divided into several compartments.

A vessel drawing 15 feet water could by this means be made to draw only 11 feet, and the largest man-of-war in the Dutch service could be made to pass the sand banks of the Zuyder Zee. Meuves Meindertszoon Bakker invented this curious machine at Amsterdam about 1688: it has been used at Venice, on the Tiber, and elsewhere with success.

The camel is an excellent example to show that when a body is held beneath the surface of a fluid, the force with which it will ascend, if it be lighter than the fluid, or with which it will descend if it be heavier, is equal to the difference between its own weight and the weight of an equal quantity of fluid. Ice by the same means can remove enormous masses of rock, it being specifically lighter than water: when a river is frozen, and large stones surrounded by ice, the upward pressure of lift exerted upon them so far exceeds that exerted downwards, that they are brought to the surface, and then floated by the ice, and often carried to a great distance.

The Pontoon, made either of timber or copper, acts somewhat upon the same principle: when applied to close the mouth of a canal or entrance to a dock, they are sunk or raised by either letting in or pumping out the water they contain, and it is by an adjustment of its contents that it can be kept at any height, shown by the lines figured 1, 2, 3, 4, 5, 6, 7, 8, 9. If it be required that water should pass to or from the canal or dock, the pumps which are within the pontoon are worked sufficiently to lighten it and allow it to rise, or if it be necessary to lower it, this can be effected by admitting the water within it, by means of a pipe and turncock, shown in the transverse section. The letters A, B, C, D, E, show the width of the corresponding parts of the plan and end elevation, as do the figures marked upon it and the transverse section. Such a contrivance working in two grooves effects the same purpose as lock-gates, but when it is required to allow the passage of any vessel, it is necessary that the pontoon should be floated out of its position and be moored aside: such pontoons or lighters are found serviceable at ferries and piers, where the height of the water varies with the tides.

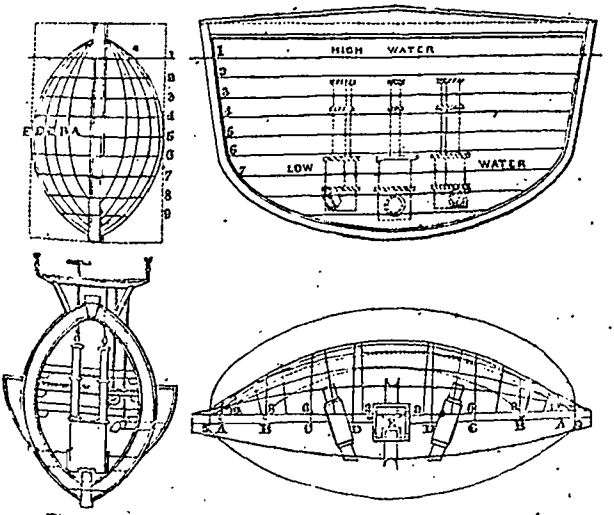


Fig. 1620. PONTOONS.

Raising Vessels when sunk at Sea: one of the most celebrated efforts of this kind was recorded by the senator Zusto, by order of the Venetian government, after the ship of the line of 74 guns, named the Phœnix, which had sunk in the year 1783 in the canal of Spignon, near the entrance of the Lagune, was raised by the Chevalier Morelatto, a distinguished naval officer in the employ of the republic.

The Phœnix, sunk in a depth of 36 feet of water, and bedded several feet in the mud, was considerably injured by the concussions it had experienced in its descent; it was therefore necessary, not only that the weight of the vessel should be sustained, but that

also a power should be applied that should overcome the suction, as well as the mass of mud with which it was filled: to effect this, a power equal to 3¼ millions of pounds was required. Two methods were adopted, each of which was sufficient for the end proposed, and the vessel would have been raised by the first, if a violent storm at the moment it was lifted had not disengaged and deranged the apparatus, and allowed it again to sink: that first employed consisted of forming below a large and strong platform, with eighteen pieces of timber, nearly 100 feet in length, bound together with five rows of other timbers laid in a transverse direction; this frame was attached to the sunken vessel by cables passed through its port-holes: four vessels were placed under the frame by filling them with water, and when they were secured to it, a ship of the line was disposed at its side, and five smaller vessels near the prow. On the first were ten capstans, which worked a running tackle made fast to the sunken ship, and on the other five were placed seventeen other capstans, which worked a tackle attached to the head; they emptied the four vessels filled with water, and at the same time turned all the capstans together, and by this process raised the vessel, which, as has been observed, again sunk: in the second attempt they made use of the capstans as before, but instead of the submerged vessel, they employed sixty other capstans arranged upon a platform, placed over another seventy-four, two smaller ships, and two enormous levers.

The seventy-four gun-ship which was employed had three strong shears or derricks mounted on the deck, secured to the masts, and partly by arrangements made in the hold below; besides these were eighteen others of a similar kind, but smaller in dimensions, which rested on the upper deck, and provided with as many windlasses: a platform was thrown out on the opposite side to that where the submerged vessel was level, with the deck, and at the ends of the timbers, which projected as much as two-thirds the breadth of the seventy-four gun-ship, were suspended casks and boats loaded with stone, for the purpose of keeping the works steady, when the whole of the thirty capstans, which were mounted on the platform and deck in three rows, were at full work; the three sets of great and the eighteen lesser derricks served as the points of suspension to the tackle, which the thirty capstans and eighteen windlasses worked.

Another apparatus of a similar kind was arranged upon a platform built over two lesser vessels on the other side of the submerged ship, and, to render the whole sufficiently buoyant, a number of large casks was attached in a circle: smaller platforms were established at the head, and another at the stern, each of which carried an enormous piece of timber, slung in a manner to act as a powerful lever; another served to moor a part of these preparations, and rows of piles, wherever they could be driven, were made use of; after every precaution had been taken to render the arrangements steady, 600 men at one time applied their strength to the capstans and windlasses, and raised the Phœnix by degrees; when it had been raised 15 feet, they moved the whole of the works, together with the sunken ship, along the canal, and commenced its demolition: in preparing the works, and accomplishing this mighty task, upwards of two years was consumed, besides an enormous quantity of timber, iron, cordage, and labour.

In France, they have adopted several methods to raise vessels which have foundered or sunk in situations where it was necessary for the purposes of the navigation that they should be removed.

A vessel sunk at the mouth of the Loire was raised by Bonvaux after it had been in its position twenty-four years: his method consisted in passing four cables, by means of an iron bar, under it; the bars being formed in a manner to suit the curve of the ship's side, which he had ascertained as well as he could; this curved iron bar was pointed at one end, and provided with an eye at the other, through which the cables might be passed and drawn under the keel. This bar, formed on an arc of a circle, resembled, when mounted, a part of the felly of a wheel sustained by four of its spokes, whose central termination was threaded by a stout bolt, which answered the purpose of the nave or axle round which the wheel turned. The bolt passed into a vertical piece of timber, fixed at the lower end by means of an iron fork in the ship's hull, and at the upper into some stout framing secured to some strong piles, driven for the purpose.

When the point of the bar was introduced and partly driven into the ground, the first spoke or radius of the wheel was released by removing a screw, and when the bar exhibited its point on the other side, and it was sufficiently driven or forced through, they employed a three-toothed fork, the prongs of which entered into holes previously prepared in the iron bar, and then by main force pulled it through; a running tackle was then applied, worked by a capstan placed on the deck of a small vessel moored near for the purpose.

After four cables had been passed under the sunken ship, two barges were moored over the hull of that bedded in the mud, on which four stout timbers or masts were laid; to these were attached the ropes, firmly secured; when the tide rose the whole became buoyant, and four or five tides enabled the sunken vessel to be towed on shore, where it was left at low water, to be demolished or broken up.

The method adopted by Goubert to raise a sunken vessel which had lain 42 years in the roads of Renondelle was somewhat similar; its depth was 17 feet at low water; the bar made use of was the mast of a ship 33 or 34 feet in length, armed with four flat iron bars, and pointed at the end with an iron rod 23 feet long; the two ropes which were to be passed under the hull were attached to this point, and, previous to this being attempted, Goubert dug small channels in the mud, one of which he made perpendicular to the keel, and another he formed on the opposite side in an oblique direction: after introducing the mast into the first-mentioned hole, and placing it by means of tackle in an oblique direction, with a pile-driving engine he forced it through the mud into the channel cut to receive it on the opposite side, and then fastened a rope to the iron point; the wooden mast was then separated from it, and, by means of three capstans, the ropes were pulled through, and when all were passed under the vessel, they were made fast to two rafts prepared to receive them, and, by means of the tide, the whole was worked into shallow water, where it was demolished.

Another method adopted when the position of the vessel which has been sunk is thoroughly ascertained, is to employ two vessels to pass a chain cable under or around her: these are placed near the bow, with the cable suspended from one to the other in such a manner that it sweeps along the ground; the chain is then moved backwards and forwards until it comes under the sunken ship; the two vessels are then moved astern, and the ends of the chains are brought together, and passed through an elliptical ring sunk close to the stern, the ends of the chain being made fast: when this main chain is in its required position, others, called bridle chains, are fastened to it at various convenient distances, and also to other vessels at the time of low water; then, as the tide flows, the vessel sunk is elevated, and afterwards floated to the shore.

Hedgehog, in use for removing mud in rivers, or the accumulation on the land side of sea-sluices: it is cylindrical in its form, like a garden roller; around the outside are attached eight or more longitudinal ribs, each of which is armed with as many spades or hoes fixed in them firmly by bolts and screws. This cylinder revolves on pivots in gudgeons in the side frame, which is made of oak, and diagonally braced in front of the roller or the revolving cylinder. The iron spades are in width 4 inches, and in length 7, and are placed about 7 inches apart: at each end of the shaft is attached a strong chain, by which its motion is insured, and when used it is attached to the stern of a barge, which in Lincolnshire is usually drawn by horses; sometimes a barge is moored at some distance from the mouth of the sluice to be cleansed, and the hedgehog is moved backwards and forwards by blocks and chains: such a machine made of oak, and well bolted together, is most effective; as the cylinder revolves on its axis, its sixty-four spades are all brought into work, and in their progress disturb a vast quantity of mud, which the stream through the sluice aids in carrying away. The timber frame has its scantling 6 inches by 4, its cross-stays from one side to the other being placed about 3 feet apart; and between them are introduced diagonal braces, which are made fast to the frame and stays by iron bolts. The stocks on the cylindrical drum or iron wheel are in length 6 feet, and made of oak 6 by 4 inches, into which pass the iron spades.

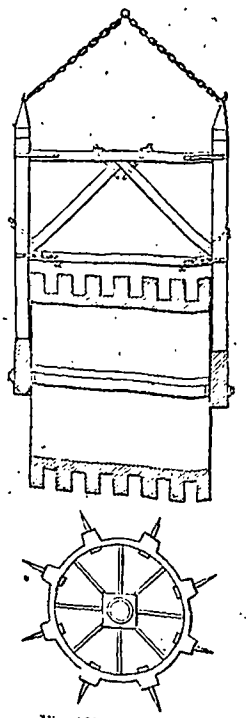


Fig. 1621.

Floating Clough, for scouring out the channel of a river at Great Grimsby, as well as other channels of the Humber. A frame 12 feet in length, 9 feet in width, and 6 feet deep, of timber 6 by 4 inches, covered with 2-inch plank; through the middle is a culvert 2 feet 6 inches in width, made with planks, with a small lifting door at one end. At the bottom is secured two beams, which project in front, and which serve as feelers to keep the machine in its right position: in the front are placed frames of timber shod with iron, cut in a serrated form, which, by means of a lever, can be raised at pleasure: at the sides of the machine are wings, sloped to accommodate themselves to the fall of the banks, and when the water is at high tide it is moored into the middle of the stream, with the wings extended by means of ropes, and at half ebb the water is admitted by plugs, and the machine sinks to the bottom; the plugs are then replaced, and it remains in this position till full ebb; the iron shod frames, with teeth like a saw, are let down in front, and the whole machine being forced along by the tide, scrapes up the bottom, and the mud disturbed is carried along with the return tide for a distance of three miles or more in the space of two hours.

Dredging forms a very important part of the work of the civil engineer, and is effected in various ways; either by drags or scoops, or rakes, or machines. There are two sorts of hand-drags, one for raising mud, the other sand; the first consists of an iron box pierced with holes, open in front as well as at the top; to this is attached a slightly flexible handle, of a length proportionate to the depth it is to work in: when this is made use of, the men in a boat make the iron box enter the sand, sustaining the handle on the shoulder, and when it is filled they raise it, and if there be any large stones they are disengaged by means of hooks: a man will raise in this manner, where the depth is not more than 4 or 5 feet, a cube yard in the course of a day, and sometimes more.

The Drag for Mud is differently formed: it is an iron ring, to which a canvass bag is attached, by passing a cord through holes made in the ring purposely to receive it: that point of the iron rim which is intended to touch the ground and enter the mud must be sufficiently strong: two men in a boat or punt are required to manœuvre it, and in the course of a day they will raise from 12 to 14 cube yards, if the depth does not exceed 6 feet: when the boat is made use of, it is first moored in such a manner that it cannot drift, and in this way the canals at Venice are still dragged; such a drag allows the water to flow out of it, and retains only the solid matter.

The Louchette, a kind of spade, or a collection of them, is used for cutting or extracting turf under water, without the necessity of first pumping it dry: this consists of a light iron frame, which is armed all round with a cutting blade, in length about 3 feet; the part between it and the handle is open, being formed of four horizontal rods, and two vertical ones; these receive the turf after it is cut and detached, and enable the workmen, by means of a rope and windlass, to pull it up; these cutting instruments have a variety of forms given them to adapt them to the peculiar work they may have to perform.

The Box Shovel consists of an open box fixed at the end of a long handle, usually made of iron; the cutter traverses in a groove, and is worked by another handle; by this the turf is cut and detached, and each successive piece falls into the box: as many as four turfs may be thus drawn up at one time.

The machine at Venice probably first suggested our modern dredger; it consisted of an oblong pontoon, covered in, on the deck of which the machine was worked; its length was nearly 50 feet, and its breadth a little less than half; below the deck the space was used by the workmen as a lodging place. The mechanism attached was a large wooden beam, which moved on a pivot in its centre: this beam was formed of tapering pieces, about 50 feet in length, and together 3 feet in thickness; there were five rows, bound and hooped round with iron; this strongly constructed beam was furnished at one end with two nuts, into which worked a perpendicular screw of beech, upwards of 30 feet in height, and about 14 or 15 inches in diameter. This screw worked in a socket or plate, fixed at the bottom of the pontoon, and this being provided with a windlass below the deck, the screw was made to elevate or depress the huge wooden beam, which usually lay in a horizontal position.

At the other end of the beam, a large iron spoon was worked, which had by means of pulleys an alternate motion of rotation given to it by two vertical cylinders placed within the pontoon: the iron spoons were opened and shut by ropes and pulleys, and the dredging action was commenced by slightly depressing, then raising the beam; by the first movement the cover was moved, by the second the spoon was opened; after it had filled, it was again covered and lifted out of the water: such a heavy complicated apparatus consumed much labour, and required to be moored very strongly to the place where it was worked, and the manœuvring of the perpendicular screw, which gave movement to the weighty timber beam, was attended with painful and laborious exertions.

Eight men were required to work it, and they generally raised in a day about sixty cube yards from a depth which did not exceed 14 or 15 feet: when a greater number of men were employed, the quantity raised was proportionably greater, and twelve, which were as many as well could work at one time, have been known to lift more than a hundred cube yards. The spoon or drag contained two and a half cubic yards, and the mean time for lifting it was a quarter of an hour; thus with forty extractions in a day considerable space was cleared: such a machine was said to have cost upwards of 800 pounds.

The Chapelet was composed of three rollers, two of which touched the ground, and the other was placed above a timber scaffold, on which the soil dredged was to be raised: round these rollers worked an endless chain formed of large links, alternately flat and square: to this was attached four or more scoops or scuttles, placed at regular distances, made of sheet-iron: these were pierced with holes, and provided with a strong, projecting beak, which not only entered, but cut its way into the mud or earth below. The cylinders were armed with iron spikes which entered the square links of the chain, and turned round on pivots, working within a frame made for the purpose, of timbers sufficiently strong to retain them, and put together so that they could be raised or lowered as the depth to be dredged required. The whole was put in motion by a wheel and winch, placed parallel to the cylinders, and by which they were turned; the axis of the winch working

in a lantern turned the cylinders, and they in their motion brought up the loaded scuttles made fast to the endless chain: when either of the scuttles had arrived above the upper cylinders, it became inclined, and deposited its contents, which were immediately drawn away by a vessel or trough, and in this manner the scuttles were kept in motion and discharged.

When the depth was greater or less, the machine was made to accommodate itself by the introduction or taking away of some of the links, and mounting higher the two lower cylinders.

The winches being turned, moved the lantern fixed to their common axis; this engaging in a toothed wheel fixed to the upper cylinder, in turning drew the chain and scuttle attached to it, and also turning round, occasioned the descending scuttle to enter the ground, and to elevate the loaded one to the top of the machine, where it was thrown over, and deposited its contents upon a hinged trough, attended by a workman, who directed its further course.

Peyronnet describes a similar machine, and also furnishes the dimensions for its construction, and the cost in his time: he makes the chain 17 inches in length, and places upon it six scuttles. The cylinders were formed of elm, hooped with iron, and covered with strips of plate iron: this machine, mounted on two boats, was employed with two others at the bridge of Orleans, and each was worked by six men, who raised about twelve cube yards per day, from a depth of upwards of 6 feet: such a machine was preferred to clear out the cofferdams to the scoop previously used, which had, by means of a handle, the power only of clearing the entire width between two rows of piles; it was drawn up and down by a rope attached to it, worked by a capstan. The scuttles answered admirably well, where the bottom was not stony, but great care is requisite in the manufacture of the chains; the best were those made with bolts and screws, as they facilitated the lengthening and shortening.

We find in many of the works published in the sixteenth century descriptions of dredging machines, and at the commencement of the following century, Savery patented an invention for raising ballast out of rivers by steam: and Cornelius Meyer, a Dutch engineer, about the year 1680, contrived a machine, which strongly resembled the one in use, with this exception, that boards were made to lift the ballast, and a horse wheel was employed. Mortier and Hertel, Dutch engineers, also turned their attention to this subject, and Balme made a vertical wheel, which worked between two boats armed with six buckets, which lifted a vast deal of mud; these and many other inventions were brought over to England, and used in the time of Charles I. for dredging the fens, both in Lincolnshire and Yorkshire; and from them great improvements were afterwards made: from the evidence of Mr. Watts, we find that in 1796 he manufactured an engine for dredging to be employed in the harbour at Sunderland.

The Bag and Spoon, which has succeeded the box-shovel, consists of a ring of malleable iron, 2 feet in diameter, and 2 feet 4 inches deep, sharpened and steeled on the under side, 4 inches broad, for about one third of its circumference, and pierced on the inner edge with holes for the lacing of the bag. The remainder of the ring is of round iron, 1¼ inch in diameter, and on the upper side, or that opposite to the mouth, a hose is welded to receive the pole or handle, the length of which must be in proportion to the depth to be dredged: on each side, about half way up the spoon, is fastened a chain 30 inches in length, which is united by a ring at top, where the working rope is made fast: the bag is made of strong tanned leather, about 3½ feet in depth, laced with leather thongs to the spoon, and a sufficient number of holes is pierced through the bag to allow the water to escape. A flat-built barge, of thirty or forty tons burthen, is usually employed to work this machine, and all that is required is a small projecting crane, so made that it can be readily thrown out of gear.

The Bucket dredging Machine, worked by steam, is now universally adopted to deepen all navigable rivers, harbours, and docks, or wherever any accumulation of mud or sand is required to be removed. The contrivances of Perronet, and other French engineers, applied to the machine early used at Venice, no doubt gave rise to the introduction of this very powerful one, now almost indispensable in all ports.

Mr. John Huges seems to have been the first who used it in clearing out the bed of the Thames, about the year 1804; that originally contrived was apparently very defective, but after expending a considerable sum of money, he brought the machine to such perfection, that in one day he was enabled to raise, opposite to Woolwich, 2000 tons, where there was a depth of water of more than 30 feet. On this occasion it was constructed in an old bomb-vessel, and had a thirty-horse engine, the whole costing nearly 8000 pounds. In all probability it was similar in plan to the first, made by Boulton and Watt, which was fixed in a boat, and had four rollers, each of which had one spoon; the rollers were made to move at the rate of 10 feet per minute, and each spoon could bring up 15 cwt. at a time.

The machine employed by the Hull Dock Company in 1802 had eleven wooden scuttles working on a ladder that passed over rollers, the motion given by a horse-wheel: those now used in the harbours and navigable rivers, worked by powerful steam-engines, have a

series of iron or copper scuttles attached to a chain, which like a chapelet works round a beam elevated at the side of the vessel, and brings up large quantities of ballast at each dip.

The fly-wheel of the dredging machine is turned by a large spur-wheel, fixed on the shaft, acting in a pinion on the axis of the fly-wheel, to give it a greater velocity than the crank, by which means a smaller fly-wheel is sufficient to regulate the motion of the engine.

The motion is conveyed from the steam-engine to the chain barrels by the inclined shaft, shown in the section; at the lower end is a bevelled wheel, which receives its motion from another fixed on the main shaft of the engine. At the upper end also of the inclined shaft is another bevelled wheel, working in another fixed to the shaft, and situated in a line with the centre of the two chain barrels: at the two extremities of this shaft are two wheels, which communicate power to the chain barrels, and bring up the ballast; an engine of 16 horse-power, dredging on a moderate depth, will raise 35 tons in an hour, and consume about 343 pounds of Newcastle coal in that time.

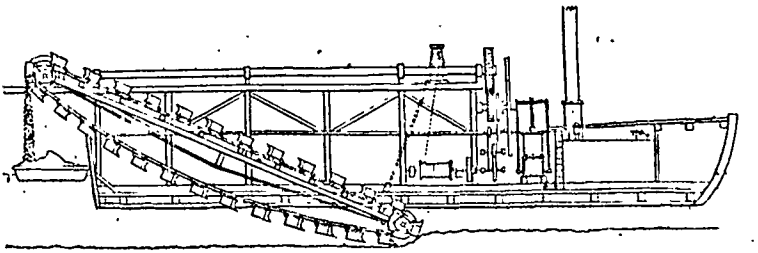


Fig. 1622. DREDGING MACHINE.

The upper rollers is a square barrel, as is that at the lower end, and around them passes the double endless chain, each alternate link of which carries a bucket; these are pierced full of holes, to allow the water to drain out as the sand or gravel is brought up. The mouths have a semicircular form, to prevent their sticking fast during the operation.

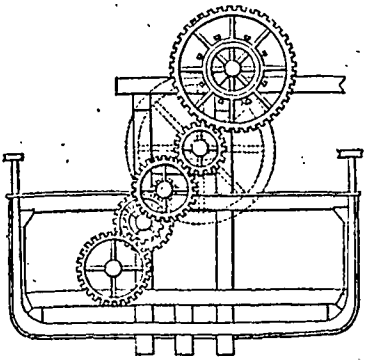


Fig. 1623. DREDGING MACHINE.

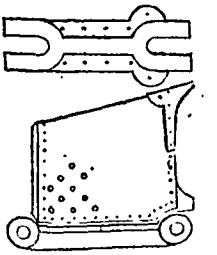


Fig. 1624. BUCKET.

Dredging machines of this kind are usually mounted in the hulk of an old sloop of 100 tons burthen, and no expense should be spared in making it strong and substantial; for after the machinery is introduced, the smallest twisting of the vessel occasions fracture of the wheels, or some other portion. The bucket frame is found to work best when at an angle of 45 degrees.

Artesian Wells have been considered of great importance, since their introduction near London in 1794, when one was sunk at Norland House, on the N. W. of the residence of Lord Holland at Kensington, and which is described in the Philosophical Transactions of 1797.

The water was derived from sandy strata, of the plastic clay formation, but so much sand was brought up, that the pipes were constantly obstructed: it was therefore found necessary to pass through the loose strata, and obtain the water from the chalk.

M. Hericart de Thury, M. Arago, and M. Von Bruckmann, have all drawn attention to this subject, and shown that throughout Europe there are extensive districts where, under certain conditions of geological structure, and at certain levels, water may be raised to the

surface by boring, and that in many instances the supply will be sufficient, as in Artois in France, to turn the wheels of corn-mills.

In the tertiary basin of Perpignan and the chalk of Tours there are subterranean rivers, which have enormous upward pressure; the water rises near Rousillon in an artesian well upwards of 40 feet above the surface, and M. Arago describes its force as sufficient to elevate a cannon ball placed over the mouth of the pipe.

M. Von Bruckmann sank an artesian well at Heilbronn in Wurtemberg, where the water was sufficiently warm to heat a paper manufactory; similar wells are in use in Alsace, and near Stutgardt.

In the Duchy of Modena are numerous artesian wells, as there are also in America, Asia, and Africa: wherever impure water is arrived at, it is necessary to continue the operation of boring until that desired is attained: the supply of water in these wells is generally referred to the same principles as the play of an artificial fountain, and their failure may be attributed to the rents and faults which abound in rocks, or to the dip of beds, which carry the fluid in another direction.

The well bored at Sheerness was continued through 300 feet of clay, below which was a bed of sand and pebbles, which when pierced, the water immediately arose: in another situation this water was obtained at a depth of 328 feet below the surface clay.

In 1824 a well was bored at Fulham, 317 feet in depth, which, after traversing the tertiary stata, was continued through 67 feet of chalk, when the water arose, and was discharged at the rate of 50 gallons per minute.

In the gardens of the Horticultural Society at Chiswick, the borings passed through 19 feet of gravel, 242 feet of clay and loam, and 67 feet of chalk, after which the water arose to the surface through the whole 329 feet. At Sion House, a short distance beyond, the boring was continued to the depth of 620 feet, so as to enter the chalk, when the water rose in a considerable volume, 4 feet above the surface.

In an artesian well sunk at Hammersmith water rose with a considerable force from a depth of 360 feet, and at Tooting another threw out sufficient to turn a water-wheel. By the borer it was found that, at St. Ouen in France, there were five distinct sheets of water, from each of which a supply was obtained; in the third, which was at a depth of 150 feet, was a cavity in which the borer suddenly sank a foot or more, and the water rose immediately in a considerable volume.

In the older geological formations, it is useless to attempt the construction of an artesian well, and among transition and secondary formations, there is seldom an abundant supply of good water: ir France, it is in the tertiary formations where the artesian wells succeed best, as that recently formed at Grenelle.

In some instances shafts have been sunk increasing in diameter, lined with iron or masonry, and strengthened in their descent: these have passed through sheets of water down to a solid stratum, beneath which pure water has been found, and conveyed by an upright pipe to the surface.

Boring. — A well 6 feet in diameter is sunk to the depth of 8 or 10 feet, and one man above and two below are enabled to carry on the operation: over the well, is laid a horizontal pole made fast at one end, and the other is operated upon as the man above gives it a slight up and down motion, to suit the action of the two below, it having a chain around it, connected with the cross-bar to which the boring instrument is attached. This cross-bar or wooden handle passes through the socket of an iron shank, which has a ring at top, and a female screw at bottom; to this all the successive boring instruments are fastened. A chisel is first attached to the screw, and the two workmen in the well press upon the cross-bar, and force it round like an auger at the same time; this will continue to descend unless the ground is very hard or full of stones; when it becomes necessary to drive it, and by changing its position occasionally, it is to revolve: after the first hole has been well opened, the chisel is changed for a cylindrical auger,

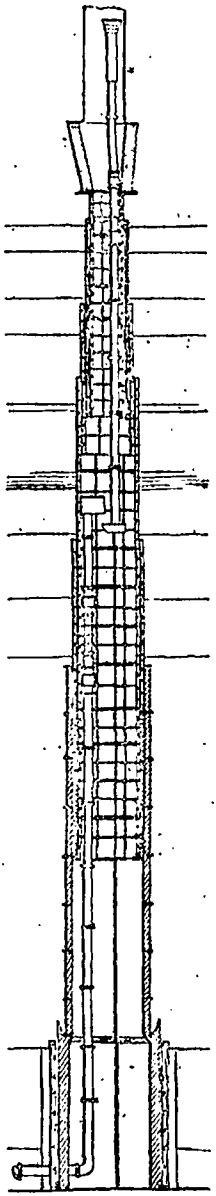


Fig. 1625. BORING.

which draws up the earth the chisel has separated; the earth entering at the bottom fills the cavity of the auger, and, as it cannot escape, it is discharged at top, and finally drawn up as occasion requires. When it is required to work the auger deeper, an iron rod is attached, by screwing it on at the upper end, and using the chisel alternately with it as before, the operation is continued: as the hole descends, additional rods are put on, and these require to be well jointed, so that they work truly. To elevate a great length of rod, it is necessary to have three poles over the wheel, secured at the top, and a pair of pulley blocks: the rods are about 7 feet in length, and as this is the usual length of haul, it must determine the position of the pulleys: a claw is used to gripe the rods to be drawn up, attached to a chain, and a wrench to unscrew the rods as they rise; sometimes a chisel 2¼ inches wide will descend 100 feet, and an auger of a little less diameter will clear the way; a chisel 4 inches in width requires an auger of 3¾ inches.

There are varieties of instruments, all of which have a screw at the upper end, tapped to one thread, and therefore easily fit into the various rods. A hollow conical instrument, with a spiral worm around it, is useful in sandy soils; a cylindrical auger with a valve in it in mud; as this is turned round, the fluid matter passes above the valve, and is secured; another form is that of the bucket, which, when dropped into the hole, acts like a pump in extracting any soft or watery matter: each of these are under the control of guide pieces and stops: when a rod becomes broken in the hole, which often occurs in rocky soils, it is drawn out by a pair of tongs which has at the lower end a cylindrical tube, above which is a chisel-edged tongue, pressed down by a spring; when this is lowered, the end of the broken rod passes into the cylinder, and pressing back the tongue, it is held fast, and thus drawn out. Punches are also required to peck into hard stones, by repeated strokes, or to break them; these are of various forms, generally angular, with outside cutting edges: when the hole is formed it is usual to line it with a metal casing about ¼ inch less in diameter than the bore; this tubing is either of tin or copper, in convenient lengths, and when sunk others are attached and soldered to it, to descend in their turn; these are driven by means of a block of wood, with an iron rod attached, which is made to traverse through a hole above; this is mounted like a pile-driver, and beats down the tubes; sometimes this is effected by fastening at the end of one of the boring rods an iron like an acorn, which enters the tube, and, by means of its projecting rim, presses it downwards. It is, however, necessary, previously to inserting the pipe or tube, to pass down the hole bored a diamond chisel, funnel-mouthed, with a triangular bit in its centre to smooth the sides and form it into a true cylinder, by keeping the chisel turned as it descends.

Well at Messrs. Truman, Hanbury, Buxton, & Co.'s Brewery in London.—The well was commenced in the middle of another 16 feet in diameter, and the work as performed by the *miser* instead of the usual methods adopted: after the land-spring in the old well had been drained, another, 11 feet in diameter, was commenced, and carried down with brick steening, the clear internal diameter being 8 feet 6 inches; after a depth of 115 feet 3 inches had been by this means arrived at, a cast-iron cylinder was lowered, and others successively were added; at a depth of 135 feet the yellow clay was reached: here the water overpowered the excavations, and the miser was again made use of; an oyster bed was then pierced 163 feet below; to drive the jumper or heavy chisel through the hard rocky crust of this oyster bed occupied the workmen seven days; when this was done the iron cylinder suddenly sank 5 feet 6 inches; the miser was again used, until the depth of 190 feet was arrived at, and the cylinders became completely fixed: soon after this, pumping was resorted to, and then a blow of sand from the bottom filled the well for a depth of 28 feet: the miser cleansed this, and the pumping again commenced, and soon after the iron cylinders separated at a joint about 73 feet from the top; a portion of the cylinder was then cut away, and, after removing the yellow clay, a dome was constructed with brick and cement entirely around the exterior of the cylinder. An internal cylinder, 2 feet in diameter, was lowered within the original cylinder, and this was continued until driven 4 feet into the chalk; the space between the large and small cylinder was filled in with granite paving-stones to a depth of 5 feet, then with broken stones, brick, and hydraulic cement for another 25 feet, to prevent any future blow of sand from the bottom of the well. The well was then drained, and 400 holes about ¼ inch in diameter were drilled in the cylinder immediately below the level of the oyster bed: the bore was then resorted to, and continued for a depth of 200 feet more, making the whole depth 400 feet, and then a supply of water was obtained equal to 33 gallons per minute: after the work was complete, and the joints of the cylinders picked out to admit the water, then, with all these sources combined, it was found to yield 81 gallons per minute, or 135 barrels in an hour, viz. 55 from the chalk, and 80 from the sand spring. The total cost of sinking this well was 4444*l.*, and the 12-horse steam engine and pumps in addition 1351*l.*

The tools vary in their form according to the material to be pierced, or in soft ground the hole may be first opened with a chisel, and then a cylindrical auger, in which the earth or broken stone passing through an aperture at the bottom, fills the cylinder, and

is then drawn up to be discharged: as the work advances an additional rod is introduced, by means of screws, which can be readily turned by a wrench, and taken to pieces as often as is required.

The operation of boring is often resorted to when it is necessary to examine several beds of earth, and to discover their nature. The engineer should on all occasions be careful to make himself acquainted with the foundations previous to his operating in any way upon the surface of the soil, and this is still more important when the constructions are under

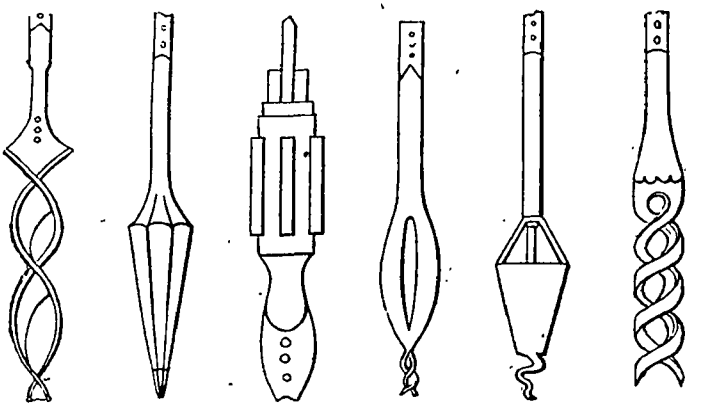


Fig. 1626. BORING INSTRUMENTS.

water: when the soil to be examined is so situated, a hollow cylindrical pile is driven down, within which the boring rods can with facility turn; at the bridge at Moulins such an operation was carried on to the depth of nearly 50 feet, and at Ambleteuse to 80 feet: at the latter place a trough was used made of planks, in lengths of 6 or 7 feet, and placed in succession one upon the other.

The borers used in France are of several kinds, and well adapted for every variety of soil: Hericart de Thury, who was inspector-general in 1810, contrived two very simple methods of uniting the boring-rods; one, by means of a fork, the other by the screw: forking was preferred, although it occupied a greater time to perform.

A more economical method of boring was practised by M. Sellow, near Saarbruck in China, who used only a heavy bar of iron about 6 feet 4 inches in length, and 4 inches in diameter, armed at its lower end with a cutting chisel, and surrounded with a hollow chamber, to receive through-valves, and bring up the detritus of the perforated stratum; it was suspended by a rope that passed over a pulley, and as the rope was pulled, the iron rod in mounting received a circular motion, which was sufficient in its descent to turn round

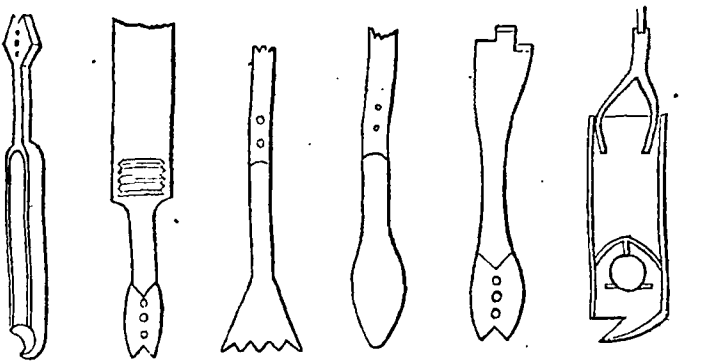


Fig. 1627. BORING INSTRUMENTS.

the chisel. After the chamber was full the whole apparatus was lifted, and the earth emptied out, when the chisel was again dropped, and the work continued: a thousand feet have in this manner been bored by the Chinese, who perforate holes in the earth 18 inches in diameter, and several hundred feet in depth, to give ventilations to their mines.

All the varieties of chisels that have been employed cannot be enumerated; those which have been found most useful have been selected; they are of different dimensions, made to suit the operations they are intended for: the chisels 2¼ inches diameter are cleared out by a gouge 2¼ inches diameter, and when withdrawn, the hole is widened by another of 3 or 4 inches in diameter, and so on: where rocks or hard bodies are to be pierced, drills of a conical form are used, and to bring up loose stones screw chisels; for clay, scoops or gouges.

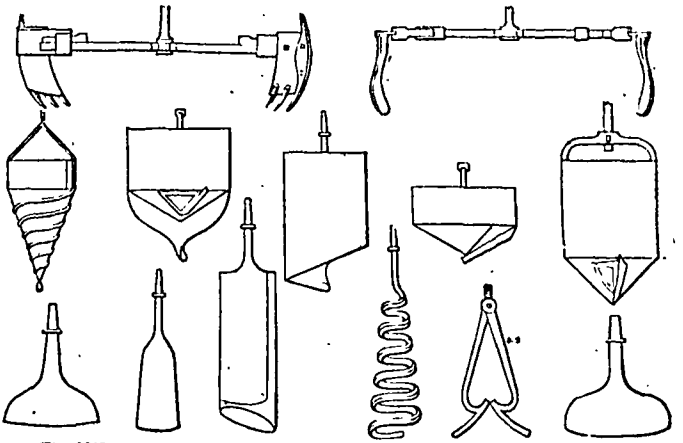


Fig. 1628. BORING INSTRUMENTS.

The tools employed by the miners consist of a pick, one side of which is used as a hammer, and called a poll, the gad which has a steel wedge, and the shovel, which usually has a pointed form, for the purpose of penetrating hard and coarse rubbish. The borer is an iron bar tipped with steel, formed like a chisel, and is used by one man holding it straight in the hole made to receive it, and giving it a constant rotation on its axis, whilst another strikes the head with an iron mallet. This hole is kept constantly cleared out by a scraper, which is a flat iron rod turned up at one end. The wheelbarrow for under ground work differs from that here represented by not having any legs; when earth is to be removed at the top, they are made generally of this form: scoops and shovels vary in their form according to their application.

In sinking the Shaft of a Mine, it frequently occurs that water is met with in such quantities, that cast-iron caissoons become necessary: in some of the deepest at Newcastle they are sunk 180 fathoms. The operation of sinking a shaft is extremely simple: two or more workmen are employed digging, whilst others at the top, by means of a windlass, hoist the soil; as the depth increases, so does the labour, and either a steam-

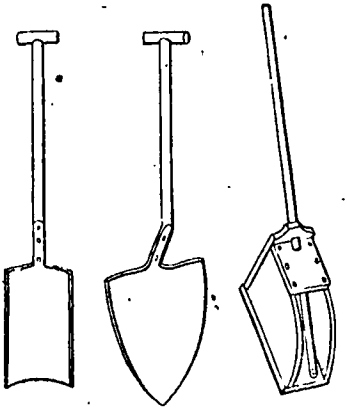


Fig. 1629. MINERS' TOOLS.

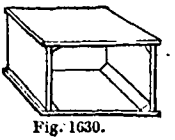


Fig. 1630.

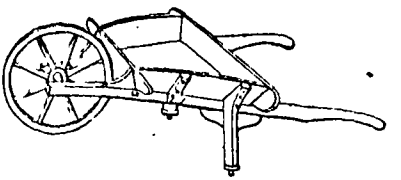


Fig. 1631. BARROWS.

engine or horse-mill is applied, called a *whim* or *whimsey*, for that purpose. The sides of the shaft are walled up or steined as it is sunk, and great care taken to prevent the

falling in of the earth; and where any water is encountered, then attention must be paid to the best method of preventing its injury to the work.

After the shaft has been sunk to its requisite depth, the several timber stages that have served the uses of the workmen are left, or others provided, to which all the requisite pipes and machinery are attached that serve to pump up the water or raise the material. The two sections exhibit the upper and lower portion of the shaft of one of the deepest copper mines in Cornwall, with the position of the ladders for the workmen to descend, and the pumps for raising the water, which with one lift and one piston often raise it 150 feet. The main rod gives motion to the pistons of the different lifts of the pumps, and is either impelled by a steam-engine or water-wheel: the pipes are of iron generally, though wood is sometimes employed.

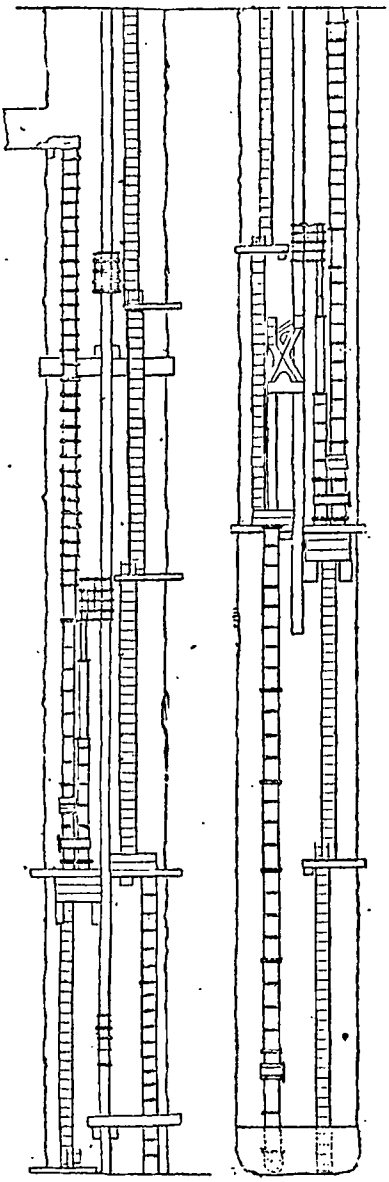


Fig. 1632. SHAFT OF A MINE.

Machines for measuring the relative strength of men and animals are usually called Dynamometers; one invented by Levoy, of the Academy of Sciences at Paris, consisted of a metal tube about 12 inches long, which was placed vertically on a stand: the tube contained a spiral spring, having above it a graduated shank terminating in a globe; when this was pressed into the tube, the force used was measured by a scale, which was graduated on the shank.

Regnier's Dynanometer resembles a common graphometer, the principal part of which instrument is a steel spring bent in the form of an ellipsis; it should be properly tempered, and well welded, and covered with leather, to prevent injury to the hands when used. This spring is represented by A A′, B B′, formed by two equal plates united at the ends by rounded half-rings. The dimensions of this spring vary according to the tension required, or the weight to which it is applied.

The dynanometer used to ascertain human strength weighs little more than two pounds, and serves to measure a thousand times that weight; its total length is about 12 or 13 inches, and its greatest breadth, as measured in the middle of the two arcs, is 2·2 inches, and the least breadth at the extremity of these arcs is $\frac{3}{4}$ of an inch. The thickness of the arcs at their centres is nearly 2 inches, and its height, which decreases from the centre towards its ends, from $\frac{1}{10}$ to $\frac{4}{10}$ of an inch: the chords of the two arcs are 6·4 inches. This length, added to that of the two demi-rings, gives for the total length of the dynamometer 12 or 13 inches. The distance between the parallel chords is about $\frac{3}{4}$ of an inch, and the perpendicular of the arcs are each $\frac{7}{10}$ of an inch, giving about 2·2 inches for the total distance between the centres of the arcs.

There are two methods of stretching the spring, by pressing it in the direction of the perpendicular of the two arcs which form it, or by drawing it with the two rings at right angles to that perpendicular: these two limits of tension are indicated by two scales drawn on the same limb, called scales of pressure and tension: the first gives the pressure of weight from zero to 264 pounds avoirdupois. The greatest pressure brings the centres

within ·4 of an inch of each other, each perpendicular, which is ·7 of an inch when there is no pressure, is reduced to ·5 of an inch. The brass limbs on which the scales are drawn is fixed on the centre of the arc A′B′ of the spring, and the opposite arc AB carries a counterpoise *ab*, 3·1 inches long; the extremity *b* of this counterpoise acts on a small branch *b*H, ·3 of an inch of a bent lever, *b*H*c*, whose other branch H*c* is a needle, 2·4 inches long, from the centre, H, of rotation to the index, *c*. Below this index is a small cylindrical thread, ·1 of an inch, which is fixed to the needle H*c*, and serves as a foot when it turns on the centre H, parallel to the limb. This first needle by turning communicates a rotatory movement round the centre K to another needle K*dd*′, which rolls on the smooth portion of the screw K, and leans on the limb by a foot G furnished with a washer to reduce friction. This second needle has two indices *d* and *d*′, to mark the pressure and traction; it is moved by the first needle H*c*; the divisions of the arcs described by the two indices are numbered in pounds, which indicate the weight brought by the needle to these divisions: as long as the spring is not stretched, the needle H*c* preserves its primitive position, and the needle K*dd*′ of the scales remains on the divisions

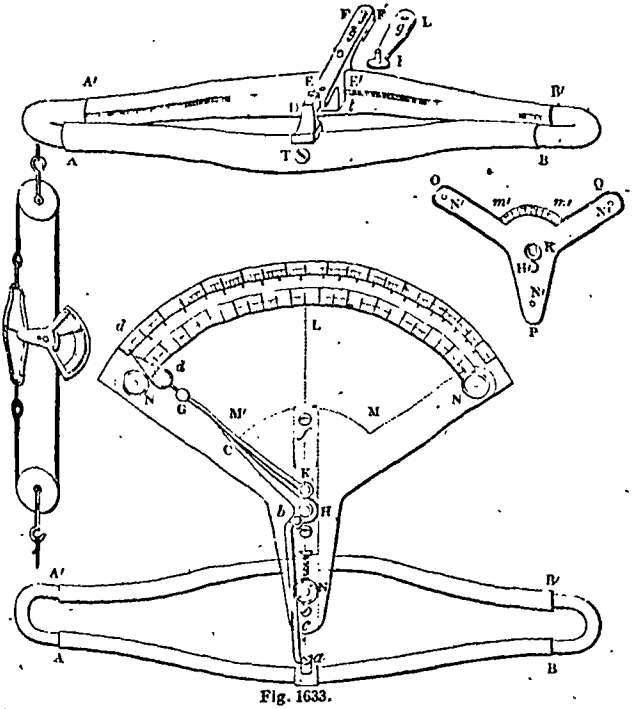


Fig. 1633.

to which it is drawn by the tension of the spring; whence it is seen that the system of two needles gives us the power of preserving the measure of a tension, when the force which produced this tension no longer acts. The greatest arc which the needle H*c* can describe is determined by the course of the counterpoise *ab*, which is ·39 of an inch. The points *b* and *c* of the bent lever G H*c* describe arcs of the same number of degrees: with regard to the positions of the two needles H*c*, K*dd*′ to the right line H K L of their centres, the angle *c*K L, which the second needle makes with this right line, is equal to the angle *c*H L of the first with the same right line, increased by the vertical angle H*c*K of the two needles, for in the triangle H*c*K, whose sides H*c* and H K are constant, the angle *c*K H is the supplement of the angle *c*K L, and of the sum of the two angles *c*K H and H*c*K. The distance H K of the centres H and K is about ·46 of an inch, and it results that the total arc described by the needle K*dd*′ is nearly one-third of the circumference.

To preserve from injury the system of these three pieces, viz. the counterpoise *ab*, the bent lever *b*H*c*, and the needle with two indices K*dd*′, the limb is covered by a plate N N N, which rests on the three pillars, ·39 of an inch high. If the axis of rotation of the bent lever were prolonged, it would meet this plate in the point H′, the centre of the arc of a circle *m*′*m*″ which terminates it, and whose radius is equal to the length of the needle H*c*. The divisions of the arc *m*′*m*″ are figured, and the figures indicate the same tensions as those on the scale of traction.

The dynanometer just described indicates on the scale of traction a tension of a ton weight, which is greater than the most powerful effort of a horse, but nevertheless too small to measure the ordinary effort of a power applied to a screw.

M. Regnier constructed a dynanometer on the same principles, which measures a traction of 6600 lbs.: the spring was of the same power and length as the old one, but the two arcs or plates of which it was composed were longer, thicker, and further apart in their centres; their distance from each other was 4·5 inches; by the greatest traction it was only diminished ·4 of an inch; these arcs had in the middle a breadth of 1·8 inches and a thickness of ·2 of an inch; the total weight of the instrument was 5½ lbs.

By placing the machine between the two ends of a cord passing over two or more pulleys, the ratio of the force which separates the extreme pulleys to the tension of the cord will be known, and by this disposition we can measure a traction much more considerable than that which is indicated by the scale of the dynanometer. Fig. 1633. shows the arrangement with two pulleys.

Details of the Construction of the Dynanometer. — Two supports D, D′, of steel, are adjusted solidly on the two opposite branches of the spring in the direction of the perpendicular of the axis. The first support D, cut in a fork, carries a screw on which the extremity *a* of the counterpoise *ab* rolls; it is about 1·4 inches high, and ·59 wide; it is retained on the centre of the arc A B by a strong screw, whose head is marked T on the convex part of the arc. The second support D is also retained by a screw, the extremity of which, *t*, is seen on the concave part of the arc A′ B′; the upper face, E, E, of this support is about 4 inches long: on the opposite face, E F, which is of the same length, is a brass plate, I L, fixed by a single screw *g*, which is level with E F in *g*: the plate, hardened to make a spring, carries at its extremity a pivot I, which passes through the support and the limb; this pivot, like that of a compass-needle, serves as a centre to the bent lever *b* H *c*: the limb is applied to the face E F, of the support D′, and is fixed there by two screws *e*, *f*. The plate I L being a spring, the pivot I yields to a pressure of the counterpoise, and prevents any rupture of the mechanism which turns the needles of the scales.

The covering plate O P Q is voided at K′ in a small circle of a diameter nearly equal to that of the head of the screw K, round which the needle K *dd* works, with a slight friction on the limb: if this friction be too slight, a turn-screw which passes through the circular opening K′ will tighten the pressure. The lower pivot of the bent lever *b* H *c* rolls on the pin I′; its upper pivot rolls on the side H′, which is riveted to the covering plate O P Q.

Spring Balance and Eprouvette. — The spring balance most used in commerce is formed of two steel branches A C, C B, bent at an angle of 45°; each of the arcs D *pq* E, I H *rs* G, is fixed to one of the branches and traverses the other. By drawing the rings E, G, which terminate the arcs in opposite directions, we bring the branch A C near B C; a circular scale figured from 5 to 40 indicates the respective positions of these two branches. The branch A C pushes before it a small cursor *k* of card or leather, which slides easily on the metallic wire *fg*, attached to the branch C B of the balance. To graduate the scale, suspend the balance by a ring E fixed to the branch A C, and attach weights to the ring G, which is at the extremity of the scale. The numbers on the scale indicate the tension of the spring.

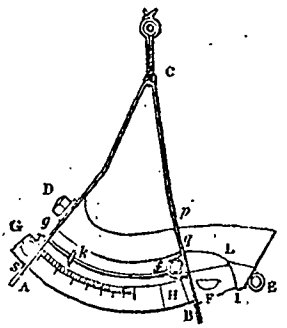


Fig. 1634.

Regnier has made an excellent instrument of this spring-balance for trying the strength of powder. The length of the branches A C and C B is about 4·8 inches, and their breadth about an inch; a small brass cannon, whose breech H is on the branch C B of the balance, and whose mouth I is closed by the fuse I L of the obturation D I L E fixed on the other branch A C of the balance, contains a given weight of powder to be tried; it is primed by a little powder put in the pan F; the powder within the cannon is fired and drives it away; after the ignition the two branches of the balance approach, and the cursor *k* indicates on the scale the tension of the spring at the moment of the explosion. The iron D E, and the brass arc G H on which the scale is drawn, pass through openings *pq*, *rs* made in the middle of the plates C B and C A.

A dynanometer for measuring animal force was invented by Mr. Graham, and afterwards improved by Desaguliers, but it was found to be inconvenient for the purpose, as it was made of wood; Leroy afterwards formed one in a metal tube 10 or 12 inches in length, with a spring within it placed vertically on a stand; this, however, was not found so useful as Regnier's, where the sides of the spring are made to approach each other, and move an index, which marks the degree of approximation on a semicircular scale; a man can ascertain by it the mean force he exerts with either hand, or with both together; it was with this kind of dynanometer that M. Quetelet, of Brussels, made his experiments upon the strength of men of different statures and ages.

Another kind of Spring Balance — The spring of this balance is bent in a curve C K D, terminated by two braces, C B, D E, one of which supports the pinion I, and the other a rack D E G H, of which the toothed portion G H catches the pinion I. This pinion and the needle which marks the tension of the spring turn on the same axis.

The face is a circle whose centre is on the axis of the pinion I, and is fixed by two screws *t* and *t'*, on the plane T V, which is soldered to the upper brace A B, which carries the pinion. To graduate the scale, suspend the balance by the ring A, and attach known weights to F by the hook δ *c*. The rack G H will work the pinion I, and the needle fixed on the axis of this pinion takes up successively the positions figured from 0 to 100; these numbers express the force of tension on the spring in pounds. The index of the needle describes about § of the inch as the maximum tension of the spring, or for the greatest distance between the extremities C and D of the spring, which is about 1·1 inch.

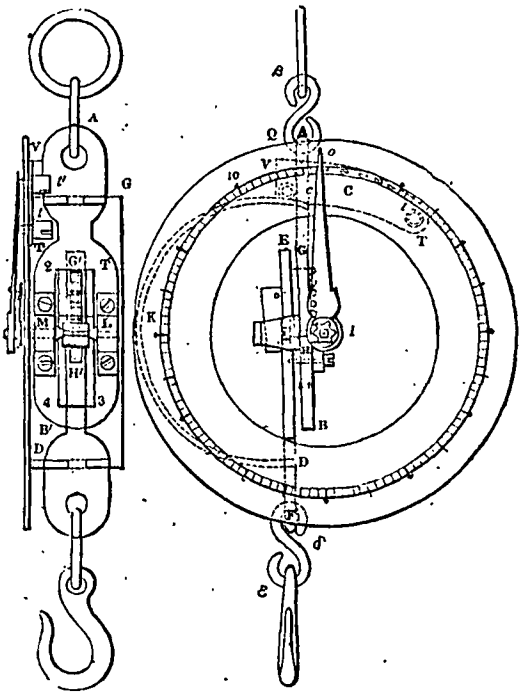


Fig. 1635.

The plane of the balance being supposed vertical, as in the projection, on another vertical plane passing through the axis of the pinion; the face of the brace A B, perpendicular to the plane of the limb, is drawn parallel to itself in A' B'; we see on this face in the parallelogram 1 2 3 4, the projection of an opening made in the thickness of the brace A B, to make way for the toothed part G H of the rack; the breadth, 1 2 or 3 4, of this opening is 4 inches; L M is the projection of the axis of the pinion I; the spring C K D is projected in C D; the plane on which the face is screwed has for its projection T V. The spring is ·11 of an inch thick, and 1·2 inches broad. To render this balance more convenient, a needle is added, which turns freely on the face round the axis of the pinion I, and may be employed as the dynanometer; it is even preferable for measuring the ordinary strength of men.

Of the dynanometric Machine, and the Measurement of the tangential Force of an Axletree. — Let A B, fig. 1636., be the section of an axle moved by water or any other power; an unknown but constant resistance acts tangentially to this axle, and we require to measure it. To resolve this question, suppose we fix on the axle A B of a wheel D E F G H, of any num-

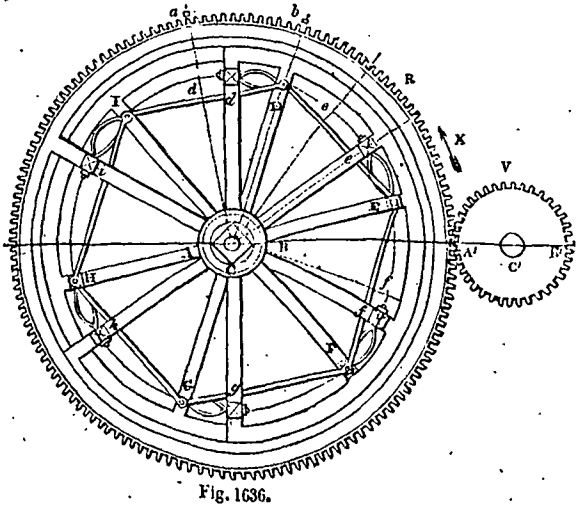


Fig. 1636.

ber of rays C D, C E, C F, &c.; this wheel turns with the axle. Another wheel having the same number of spokes, C *d*, C *c*, C *f*, turns freely on the same axle; springs D *d*, E *e*, are attached to the couples of the spokes, C D, C *d*, C E, C *e*, of the two wheels, so that the points of attachment D and *d* of the extremities of the springs are in a plane perpendicular to the axis of rotation C of the axle A B, and at an equal distance from this axle.

Having disposed the power or mover so that it shall turn the wheel freely in the direction of the arrow X, it is evident that the extremities *de*, *fg* of the springs fixed to this wheel, would swerve from the points of attachment D, E, F, &c.; that the equal angles D *c d*, F *c e*, E *c f*, &c., whose sides pass through the extremity of the springs, considered in their primitive position, would become other equal angles, D *c d*, E *c e*, E *c f*, &c., and all the other springs would be stretched, if not equally, at least at the same angle: when the total tension of the springs is equivalent to the resistance applied tangentially to the axle, the system of the two wheels will turn on the axis A B as one and the same wheel. Now suppose that the axis turns, and that we can measure one of the angles D *c d'*, at which all the springs are stretched, we shall have in the triangle D C *d'* the angle C, the equal sides C D, C *d*, and consequently the perpendicular let fall from the centre C on the side D *d*, or the radius of the circle to which the force which stretches the spring is tangential. We may, besides, observe the number of turns of an axis in a given time, whence we may deduce the velocity of the point at which the force that stretches each spring is applied. Multiply this velocity by the sum of the tension of the springs, the product will be the dynamic effect of an axis in a unity of time, for example 1″.

To measure the angle D *c d*, which moves in a plane perpendicular to the axis of rotation C of the axis A B, we fix on the lines C *d*, C D, the middle of the radii, two small hammers *a*, *b*, coupled by a spring D *d'*, which each move in a plane perpendicular to the axis of rotation C, and at equal or unequal distances from this axis, but greater than the radii of the wheels. These hammers strike two bells placed beyond on circles described through *a* and *b*; this being arranged, we can with a seconds watch measure the time which elapses between the two consecutive sounds resulting from the blow of each of the hammers on the bells, and knowing besides the time of the entire revolution of the hammers, these two portions of time will be in the ratio of the arc which measures the angle of the right lines passing through the extremity of each spring to the entire circumference. This angle being known, we can easily measure the weight which stretches each spring at a known angle, and the sum of these weights will be the total tension of the dynanometric machine.

By this description it will be seen that simple springs without needles or scales, whose force of tension for the same lengthening may be sensibly unequal, gives exactly the measurement of a tangential force applied to axes: by taking springs capable only of a tension of a ton, we may place eight on a circle of 39·37 inches radius, and eight others on a concentric circle of 8 decimetres, supposing the axle makes four turns per minute; the dynanometric machine, will show on this hypothesis that the dynamic effect produced by a force applied to an axle is nearly equivalent to that obtained from 80 horses.

Portable Dynanometric Machine.— The system of two wheels which composes the dynanometric machine, being constructed at the same time as the axle A C B, we can only measure the tangential force capable of overcoming the resistance applied to this axle: but if this first construction did not exist, or if we would avoid the expense it would occasion, we might make use of the portable dynanometric machine about to be described, and which has for its object the measurement of a tangential force applied to any axle A′ C′ B′, provided we suppose, which is always the case, that this axle engages or disengages at pleasure the wheel or pinion which communicates its movement to the resistance;

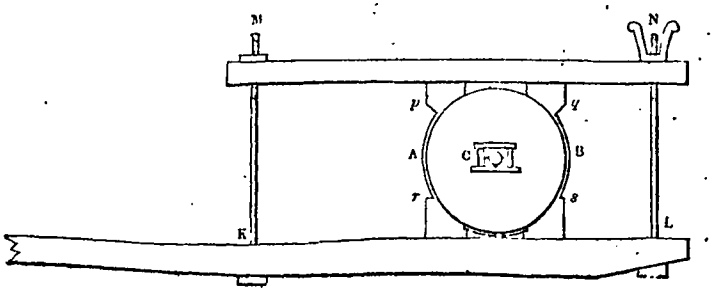


Fig. 1637.

a frame of carpentry solidly bedded and fixed in the ground near the axle A′ C′ B′, sustains the axle A C B by its two gudgeons; the system of two wheels, one fixed on this axle,

the other turning freely, is placed at the middle of its length: a factitious resistance is applied on the length of the axle, which we may obtain in various ways: conceive for example, that if the axle A C B, fig. 1637., is engaged between four blocks, p, q, r, s, fixed to the beams K L, M N, and if we bring the second beam near the first by the screws M and N, we shall increase the friction of the axle A C B on the blocks; and, by applying other blocks and beams along the axle, we may indefinitely increase the factitious resistance applied to the axle. Let us now explain the use of the dynanometric machine, fig. 1636., to measure the useful resistance applied to the axle A′ B′ C′: when the axle is subjected to this resistance its swiftness of rotation, or the number of turns which it makes in a minute, for example, is known, in disengaging or communicating its movement to the toothed-wheel R, or *defgh* of the dynanometric machine, we shall produce a factitious resistance on the axle A C B of this machine, in the same manner as the axle A C B will have the swiftness of rotation determined by the useful resistance. The springs, D, *d*, will make known the factitious resistance applied tangentially to the toothed-wheel R, or axle A C B, and consequently the useful resistance, which, by hypothesis, is equal thereto: if the means of producing a factitious resistance equal to a real determined resistance were insufficient, we shall now prove that, by a very simple calculation, one may deduce from the measurement of one part of a resistance, the total value of this resistance.

Of the tangential Force applied to an Axle, deduced from the Measurement of one Part of this Force. — An axle communicates ordinarily its motion to a mechanical system of the same kind, which can move at pleasure together or separately: suppose that by the instantaneous interruption of the communication of motion between some of these mechanical arrangements and the axle by which the power is applied, we shall diminish the resistance and increase the velocity of rotation of this axis: in this hypothesis, we may make it catch the wheel R of the dynanometric machine, whose axle is submitted to a factitious resistance, and by several trials we shall find the resistance which gives the primitive velocity to the axle by which power is applied. Let us call X the total resistance applied on this axle to the extremity of the radius I, and F the factitious resistance which communicates its primitive velocity: by diminishing the machinery moved by the axle by which the power is applied, the total resistance X becomes of a mean value, which I call X′; now these two resistances X and X′ are evidently in the known relation to the quantity of machinery turned by the axle; we shall then have $X' = nX$, n being a given number.

Further, $X = X' + F$; then the axle by which power is applied submitted to the resistance X, or the sum of the two resistances X and F, turns equally swiftly, whence it follows that $X = nX + F$, which gives for the total resistance X the following value, $X = \frac{F}{1-n}$.

We comprise in the measured resistance F, the inertia and friction produced by the communication of motion from the axle of power to the axle of the dynanometric machine, and which adds to the factitious resistance.

The dynanometer invented by Sir David Brewster, to whom science is so considerably indebted, deserves to be mentioned: that celebrated philosopher has recommended that a vessel containing water should have a cylinder, made of some heavier substance than the water, suspended in it by a rope passing over a pulley: when the upper surface of the cylinder is on a level with the surface of the water, the weight of the cylinder, or the force which it exerts upon the rope, will be equal to the absolute weight of the cylinder in air diminished by the weight of a quantity of water of the same magnitude as the cylinder: a horse or a man pulling at the rope to raise the cylinder above the fluid surface, the weight of the cylinder will gradually increase; and if the magnitude and specific gravity of the cylinder are duly adjusted to the force, there will be a particular position of the cylinder at which its weight will exactly balance that applied. The forces in equilibrio, or those required to be measured, will be equal to the absolute weight of the cylinder, diminished by the weight of a quantity of water equal to the magnitude of the immersed part of the cylinder: a scale attached may be so set out, that it will accurately measure the force applied, and the cylinder can be increased to any length by diminishing its diameter, so that a very lengthened division may be adopted.

CHAP. XIV.

ON PILES AND PILE-DRIVING, ETC.

Building upon piles has been more practised by the moderns than by the ancients, who only made use of them when it was not possible to attain a solid soil; it was not their custom to lay upon them a platform of carpentry, but, after cutting off their heads at the level, or a little below the soil, they covered them with charcoal to prevent decay, on which they spread a bed of rubble or coarse concrete, which acquired strength with age: the platforms of carpentry placed upon the heads of piles by modern engineers too often are found to decay, and the filling in of the stones being disturbed, the waters are allowed to filter through and endanger the foundation. Timber quickly perishes when subject to alternate changes of wet and dry, but remains sound for a long time under water, particularly in some soils: we have a remarkable example of such preservation in one of the piles of the bridge built by Trajan over the Danube, which when examined in the last century was found petrified; this, however, was not the case for more than the thickness of $\frac{1}{4}$ of an inch, beyond which the timber was not in any way changed from its ordinary character.

In Holland and other similar situations, planking and piling are adopted when the soil is of that description that a more solid method cannot be used, and when there is great facility of driving piles and covering them with planks fastened to their heads, after ramming between them rough stones: on this is built a construction of freestone, the first course being well cramped together. Timber and stone used together in foundations never produce solidity and duration.

When it is absolutely necessary to pile, it is better to omit the floor of planking, and to substitute a bed of concrete, which unites the masonry above with the filling in between the heads of the piles, the timber being first covered with powder of charcoal: on this bed, well levelled and rendered solid, the first courses of squared masonry may be laid.

Pile-driving has for its object the consolidation of a soil when not sufficiently compact, for piles driven close together tend in some degree to prevent that compression which might manifest itself under a heavy construction: it is also resorted to when a solid stratum lies at a depth too great to uncover, or when it is crossed by layers of soft earth difficult to remove. The nature of the soil must guide us on all occasions in the selection of the method to be adopted for work of this kind, and the qualities of the piles to be used; they should be formed of the straightest timber, the fibres of which are not in any way twisted, otherwise in driving they would bend and not arrive at the required depth; they should not taper, or the difficulty will be increased: when, however, they are driven to the greatest possible depth, in order to be certain that the soil is sufficiently consolidated, they should be loaded with a weight equal to what they are intended to bear, and this weight left a sufficient length of time to remove any doubts upon the subject. In clay, naturally firm, the pile sometimes becomes a conductor to the water, which insinuates itself along the sides, softening and producing a settling, which would not have taken place had piling not been introduced; and wherever such a soil occurs, the first piles should be driven 5 or 6 feet apart, and before they arrive at their entire depth, others should be placed in the intervals, greater resistance being experienced in proportion as the numbers are increased; and it sometimes happens that, in order to drive the latter home, or until they will drive no longer, it is necessary to place them so thick that they almost touch each other.

When it is ascertained that there is a good substratum, of a solidity and consistence capable of carrying the weight of the edifice to be put upon it, the piles may be regulated with regard to their distances, and experience has proved that when placed about 4 feet apart from centre to centre, they are capable of supporting the weight of the largest bridges; they should be always driven to their greatest possible depth, and it is advisable to commence with the middle row, as the soil then consolidates as the work is continued.

The only means of judging correctly of the resistance which a pile offers is to examine the nature of the stratum on which it bears, the hold which it takes, and whether it has penetrated a soil not susceptible of yielding under the weight of the construction, such as rock or gravel, provided this latter cannot be washed away by the current; the refusal of a pile to advance does not always insure it having arrived at a proper bed, the nature and consistency of which should always be previously ascertained: many instances could be adduced where piles have sunk under the weight placed upon them for want of these considerations.

Piles are cut off nearly at the bottom of the river, and their intervals filled in with

rubble work, in such a manner as to leave no fear of their bending under the weight; if isolated at a certain height, it is necessary that their strength should be rightly calculated, and the power of their resistance made greater than the load they have to bear; their height out of the ground should be considered in the nature of an upright piece of timber, and the rules relative to its strength and power of support duly followed. The bending and breaking of piles is not of so much consequence as their being driven out of a perpendicular position: it often happens that when they have penetrated beds of slight consistency, and have not a hold in firm soil, the foundation placed on them exerts a lateral pressure, which acting as on the arm of a lever, greater in proportion to the length of the pile, causes it to diverge; this may sometimes be prevented by inclining the external piles outwards, and driving them in an oblique direction, or in the line of the thrust to which they are subjected: with respect to the weight which piles are capable of sustaining, Perronet thinks that one of 12 inches in diameter should not be loaded with more than 50 tons, and those of 9 inches in diameter with half that weight.

Piles for foundations are either of oak, elm, fir, or beech timber: those used at the New London Bridge averaged 12 inches in diameter, were 20 feet long, shod with wrought-iron shoes, weighing 30 pounds each, and had iron hoops of the same weight, to prevent them from splitting whilst driving. The piles under the foundations of the abutments were driven at right angles to the inclination of the foundations, those for the piers perpendicularly, and the whole more than 18 inches below the under side of the platforms that were placed upon them. They were placed at distances from 3 to 4 feet from centre to centre, and when arrived at their proper depths, the heads were cut level and even, and the earth between them taken out to the depth of 9 inches below, the space between being filled with Kentish rag-stone well beat down, and racked in with sharp gravel and lime-screenings to the level of the pile-heads, on which the sills of the timbers laid transversely were spiked: when oak piles are used, their diameter is generally about the twentieth or twenty-fifth part of their length; they should be very straight, and barked and dressed with care; the head is cut at right angles to its length, and rounded to receive the movable hoop of iron; the lower end is sharpened by cutting each side to the length of about 18 inches, in such a manner as to bear upon the iron shoe, which is spiked or nailed to the end of the pile; sometimes it is only necessary to sharpen the end of the pile, and char it in the fire; this is sufficient for the scaffold pile, or for those which are for a temporary use: when sheet piling is used for a cofferdam, or the facing of a wharf or jetty, it is generally from 4 to 6 inches in thickness, and the width about 12 inches, the length of the piles depending on the nature of the soil they are to penetrate, and the depth to which the neighbouring piles have been driven; the sheet piles do not generally descend so low, and they are often required to be shod with iron; when they are to be exactly joined, there is on the side of each pile a groove, into which the plank enters, though this adds to the difficulty of driving, for which as well as for the piles the beetle is sometimes made use of, but generally a machine constructed for the purpose.

When it is necessary that either the points of the planks or piles should penetrate a hard soil, holes may be pierced with an iron-shod piece of timber or rod of iron working perpendicularly through a frame or hole cut in a large stone, which serves to guide the instrument, and the hole so formed may be sufficiently enlarged by an auger to admit them, which ensures greater stability.

The timber now generally employed for piles is either Dantzic or Memel, and too great caution cannot be used in the selection of it, to ascertain if it be perfectly sound; in some works beech or Scotch fir are employed, and if kept always under water are found equally durable: below London Bridge, on the Thames, and particularly where the water is at all brackish, the ravages made by the Teredo navalis upon fir piles is so great that a few years are sufficient entirely to destroy them above the level of low water; sheathing with copper and iron is found of little use in protecting them, as the worm enters from the mud, and pursues his ravages in a vertical direction, until the entire pile is completely hollowed out

The Three-hand Beetle is a large maul made of a block of hard wood, hooped with iron, having two long handles radiating from its centre, put at such a distance that it can be worked by two men, assisted by another in lifting it, who holds by a short handle opposite to them: this has considerable power, and is used when the piles to be driven are not of so great a length as to require the engine.

The Pile Engine varies in size and construction; when small, and the block which is let fall does not exceed 2 or 3 cwt., it is worked by a single rope passing over a large pulley, where it is divided into as many smaller ropes as may be required, at each of which a man works, and when the weight is raised, the whole let go together. This kind of machine can only be used for driving short piles, as the weight cannot be lifted beyond the height to which the men's arms can reach, but it has the advantage of being easily and rapidly worked.

For larger operations a ram of from 8 to 10 cwt. is used, set in a frame of woodwork, placed on a base formed by four timbers framed and bolted together at right angles, and to

which is screwed or securely attached a crab, with a cylindrical barrel and two handles, worked by four or six men: on this framing is placed on one side two upright pieces of timber, on the other an inclined ladder, the whole securely braced together: at the top a wheel is fixed, over which the chain worked by the crab passes, and is attached to the monkey, which has a plate in front and at the back, so that it is confined to work a saw up and down the perpendicular pieces of timber, which are protected by plates of iron.

The rope, fastened at the top, elevates the monkey, and the nippers being applied at the bottom are enabled to hold the ram until they are elevated to the inclined planes at top, where they are compressed, by which means the bottom part, which holds the ram, is opened, and it is suffered to fall the entire height of the machine upon the pile head below. The monkey and nippers immediately follow by their own weight; the latter open again, and admit the hoop or ear of the ram to be ready to be lifted by the men at the crab: the higher the ram is lifted, the greater will be the blow given to the head of the pile; the time of raising it is increased, though not in proportion to the advantages gained, but in a higher ratio, the velocity being as the square root of the height, whereas the time is as the height merely.

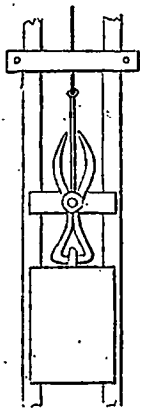


Fig. 1638.

The rams are of oak, of a cylindrical form, strongly hooped round for common purposes; but generally cast-iron is preferable, and is more durable. Coulomb valued the daily action of a man employed at the pile-engine as 75·2 kilogrammes, and capable of raising 1000 metres.

The pile is placed vertically in the spot where it is to be driven, and is generally lowered by the chain of the engine being attached to it at about one-third of its length; it is then maintained in its position, and allowed to descend until it has fixed itself in the soil; when the pile has arrived below the frame of the engine, and the ram can no longer reach it, the driving is continued by means of a false pile, or piece of timber bound with iron at the two extremities, and having a gudgeon of iron entering into a hole at the head of the pile; but grafting the piles with others securely fastened and bound with iron hoops is perhaps the most simple method, as well as efficacious, when they are to descend far into the soil.

Great care must be taken that the piles are driven in a vertical position: to insure this, and prevent their swerving during the action of driving, they are passed through a piece of framing attached firmly to the scaffold, which obliges them to descend perpendicularly; sometimes a large stone will change the direction of the point; it should then be withdrawn, and the stone be either crushed or removed; for if a pile takes a wrong direction, it is better to pull it up and replace it, than persist in endeavouring to right it: in order that the piles may each have its proper position, it is requisite to trace their places on the platform, or to fix lines, which represent by their intersection their true positions; or, where the situation will permit, stakes may be placed to indicate this, and these preliminary operations are highly necessary when the engine is placed in boats or lighters.

The same means are adopted for driving the planks as for the piles; their use being to enclose a certain space, it is highly important that their joints should be rendered as close as possible; this is done by framing together two pieces of timber on the scaffold, in the manner of a groove, between which the planks are driven.

Frames are formed by the rails, which are disposed on each side of the planks, and are secured by a pin placed in a mortice horizontal in them and vertical in the plank, in order to afford some play in the driving. The planks in the middle of the frame are driven first, and when those at the extremities which carry the rail are arrived at, the peg must be removed to the next plank, where a similar mortice has been made: a lower frame is used, when necessary, to more perfectly regulate the driving; short planks may be carried to their position, and placed vertically by the side of each other, and when made to enter a little into the soil, a blow on their heads is sufficient to establish them; they may be held in their places by a cramp or iron; driving planks as well as piles is often performed from two boats coupled together, carrying a timber frame. The same force made use of to drive the pile might be applied by machinery, but it would be difficult to construct it of sufficient strength, and free from friction: a weight, for instance, of 500 pounds, falling through a height of 50 feet, may drive a pile at each stroke 2 inches, and if the resistance be considered uniform, the magnitude must be about 150,000 pounds; the same moving power, with a mechanical advantage of 300 to 1, would perform the work in the same time; but the strain upon some parts of such a machine would be equivalent to the draught of 600 horses.

The ends of the piles are variously cut, according to the soil they are intended to penetrate: being shod with iron they are prevented from splitting as they enter a hard stratum or come in contact with stone.

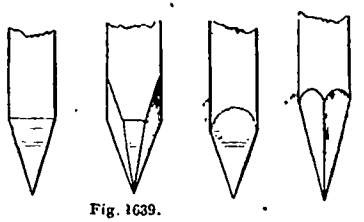


Fig. 1639.

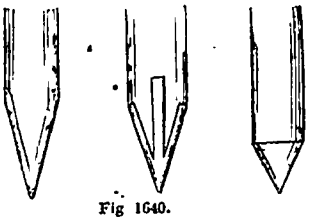


Fig 1640.

Sheeting Piles are formed of thick plank, shot or jointed on the edges, so that they may form a close joint, and not admit the water to pass between them: when their sides are grooved and tongued, the passage of either air or water is prevented; the edge of one plank is double, and the other single, rebated, so that about a third of the thickness of one passes into the middle of the thickness of the other: to drive these piles the small or ringing engine is generally made use of, and to bring the edges of the planks into close contact with each other great care is necessary: the pointing of sheet piles should be effected by cutting one side only of the plank.

Water and quicksands are often kept back by sheet piling, but it sometimes happens that both rise so rapidly as to impede the workmen's progress; the pump or other means is then adopted to drain off the water, and it becomes necessary, under such circumstances, to provide guides for driving, and afterwards retaining the planks or sheet-piles in their proper position: square timbers, placed horizontally, as well as parallel with each other, are put as near the work as possible, and kept apart at each of their ends by a short pile driven firmly into the ground, into which they are secured with screw bolts. These horizontal timbers are not laid farther apart than just to allow of the thickness of the sheet pile, which varies from 2 to 6 inches or more, according to the work it has to perform. Piles introduced between guides can be very accurately driven, and easily maintained in their position: when the resistance they offer is considerable, both the upper and lower part of the guides may be made of whole timbers, and the lower stiffened by bracing, or by short piles driven close behind them at small intervals: care must also be taken to provide for the security of the sheet of piles when the whole is complete, for during the progress of driving and fixing, the water and sand can rise to a common level on both sides; but when these are cleared out on one side to form a dam, the accumulation and consequent weight which exerts its influence on one side will break down, or force out the work, unless strutted and braced with sufficient strength to prevent it.

It is necessary, when the water is perfectly clear, to stop all the joints, or to caulk them with oakum, but generally the particles of clay or earth settle in the joints, and render them water-tight.

In the formations of a cofferdam it is frequently requisite to drive two rows of vertical piles and plank piles, and to fill in the intermediate space with well prepared clay: in other cases main piles are driven, to which are fixed strong horizontal planks, and another mode is to drive one row of gauged piles, and then fill the spaces between with pile planks driven vertically.

In deep rivers the foundation of piers were previously made by driving piles all over the space, so that their heads stood level with low water; the spaces between them were merely filled with loose stones, and the masonry, as at old London Bridge, commenced at their top; but the piers were immense masses, and required to be protected by sterlings, leaving a very confined water-way, and created a head and velocity which ploughed up the entire bed of the river below the piers: our old bridges appear to have been constructed without cofferdams or caissoons, the engineers employed upon them probably considering that weight and resistance were requisite to oppose the current of a river, and rather than yield to its force they threw in sufficient material to almost draw it up: modern practice, on the contrary, endeavours not to abridge the width of water-way, and its advantages are universally admitted, as are the employment of sheeting piles around the footings of the foundations.

The machine used by Perronet was worked by a number of ropes pulled by men; hence it was named the *ringing engine*, and the pile was driven by a ram which descended perpendicularly: the various parts of the framing were of stout timbers, put together with round iron pins, which allowed of its being taken to pieces when necessary, and transported to some other situation: attached in the rear of the supporting frame was a windlass for the purpose of hoisting the pile, or placing it into its position for driving, the rope which wound it up passing over a pulley fixed in the projecting timber at the top of the machine.

This celebrated Engineer, in the foundations of the piers of his bridges, made use of piles of from 9 to 12 inches in diameter, placing them from 3 to 4 feet apart from centre to centre, and driving them 6 feet into the bed of the river, when composed of soft mud,

clay, or gravel. The pile planks were from 9 to 12 inches in breadth, and 4 inches thick, and one frame held 16 pile planks, which were driven at one time: the frames were placed along, and embraced three of the main guide piles, and were composed of two upright timbers of the same thickness as the pile planks, and were sharpened at the end: these uprights were fastened together by two horizontal timbers, one above, the other below, and separated from each other by the thickness of the uprights: when these frames were fixed, they served the purpose of guides to the pile planks: the grooves at their sides were 2 or 3 inches wide, and as much in depth.

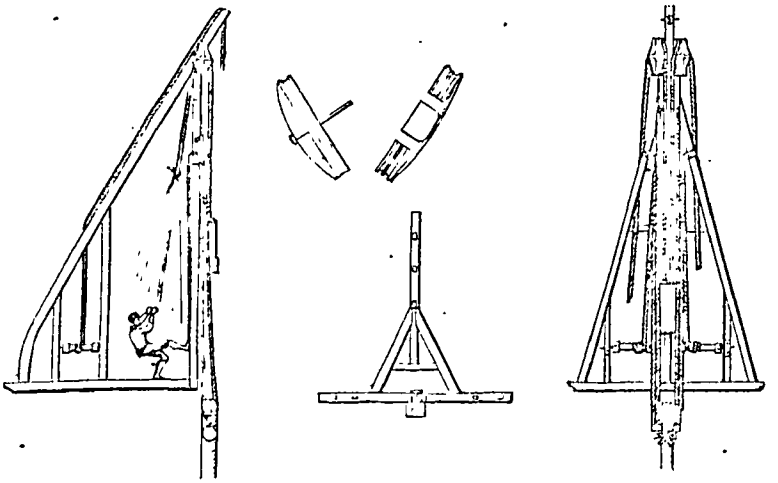


Fig. 1641. PERRONET'S PILE-ENGINE.

Perronet used a similar engine at the bridge of Orleans, and a ram for driving the piles, which weighed 1200 pounds, and another for the pile planks, of only half that weight: the windlass for elevating the pile was conveniently placed in the centre, and the pulling ropes were admirably arranged.

At the bridge of Neuilly a large drum wheel was made use of, round which a rope was wound, worked by a horse, and the weight of the rams employed varied from 1000 to 2000 pounds weight; with these the piles were driven, until they did not sink more than ¼ of an inch during 16 strokes: this method was not found convenient, although tackle and contrivances of various kinds were introduced into the machine, to regulate its action, and to prevent any accident occurring from the breaking of the rope.

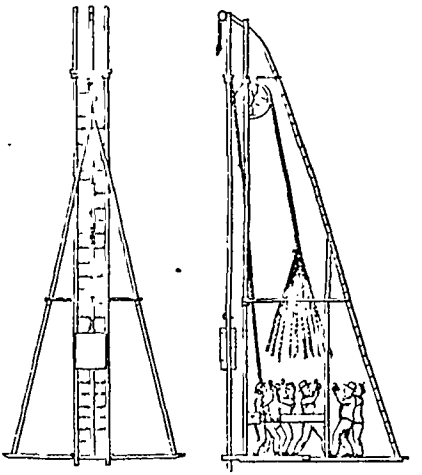


Fig. 1642 PERRONET'S PILE-ENGINE.

The dynamical effect of a horse power applied to such an engine employed in pile-driving, and worked by two horses, was found to be equal to a weight of 42,536 lbs. raised 1 foot high in 35 seconds, or a weight of 36,459 lbs raised 1 foot high per minute per horse.

When the ram is raised by horse instead of human power, the drum or cylinder upon which the rope winds ought to be provided with a *lever catch* to lay hold of the arm by which it is fixed or engaged, while the weight is rising, and which can be easily manœuvred when it is required to disengage, so that the rope may be allowed to run back, for re-engaging the weight without the slow process of turning the direction of the horse.

Perronet's pile-engine placed upon a boat, worked by an armed wheel, has frequently been found admirably adapted for its purpose; the end and side view of this machine at

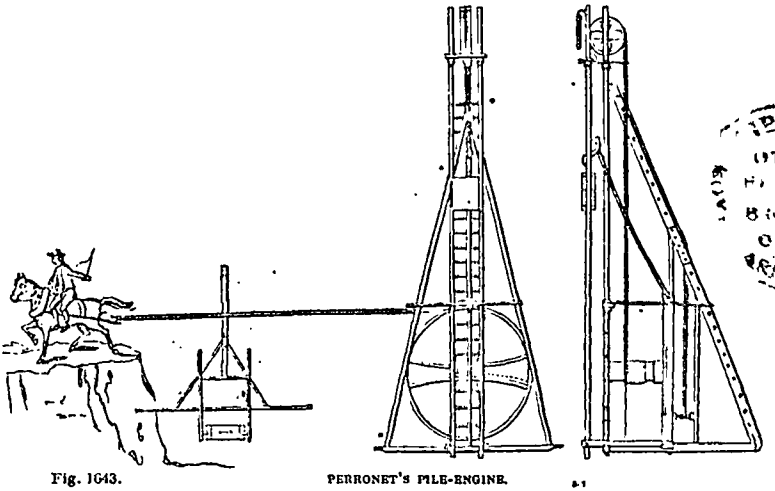


Fig. 1643. PERRONET'S PILE-ENGINE.

once show how conveniently it may be moved to perform its operations. The platform laid upon the deck of the boat being braced in all directions, the other timbers are fixed

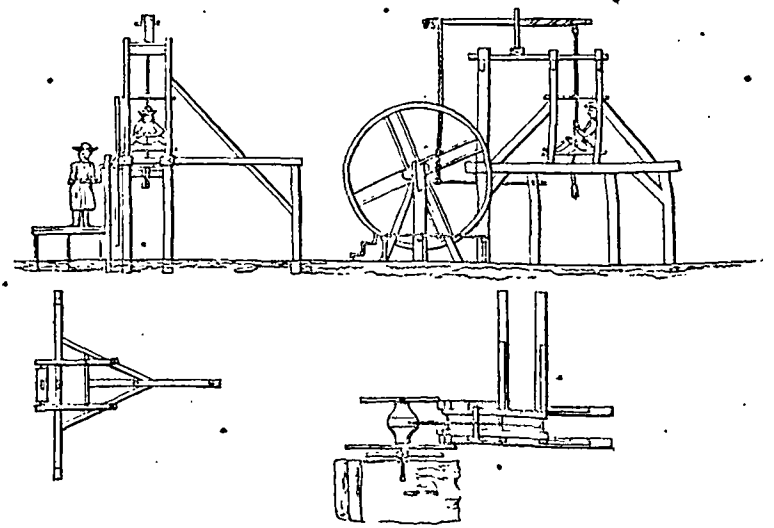


Fig. 1644. PERRONET'S PILE-DRIVING ENGINE.

upon it with facility, and may be taken down as readily when not required, and placed under cover: by means of a ladder attached to the inclined braces at the back, the upper parts of the engine could be approached, and the tackle adjusted. To keep the ram steady, it was made to slide within a frame, so that its motion could always be depended upon, and there was no danger of its falling into the water.

Pile-driver by De Cessart, used at the bridge of Saumur. — The axis was 10 inches diameter, furnished with a wheel, 12 feet in diameter, with trundles or round pins on the periphery for turning it. Eight men employed at this wheel raised at three turns a ram of 1500 pounds 6 feet high; a workman, by means of a cord, then unhooked the ram, which suddenly fell; but to regulate the height of the fall and the price for driving, it was determined that it should be limited to a stroke of 8 or 10 feet, giving the greatest fall at the time the greatest force was required to be applied to it. The price was deter mined in this case at 20 shillings per pile, including the expenses of transport, and for th scaffold piles 10 shillings.

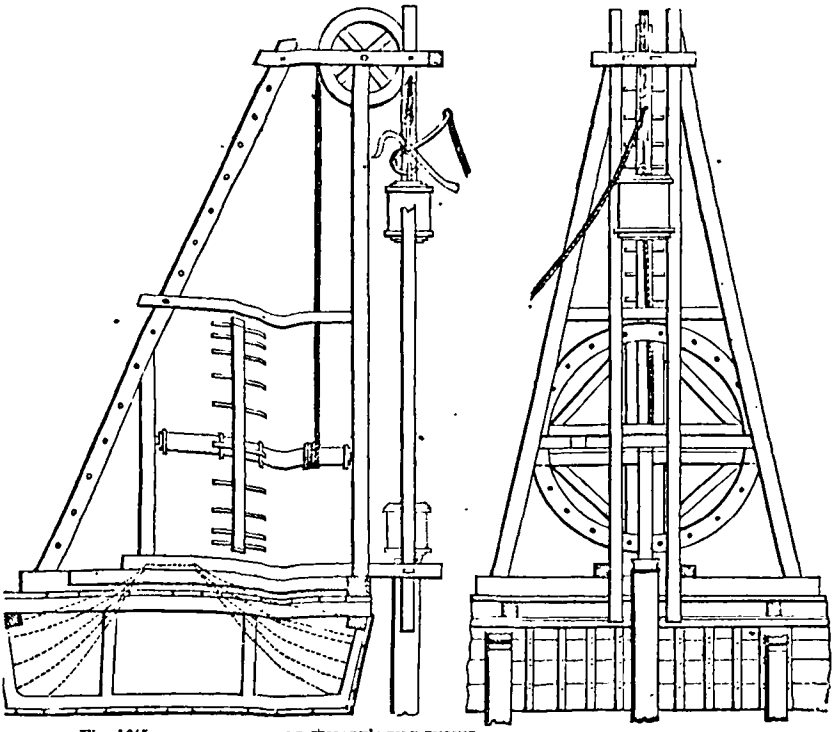


Fig. 1645. DE CESSART'S PILE-ENGINE.

De Cessart found that when driving piles into the bed of the Loire he could not make them enter more than 28 or 29 feet below the height of low water, after having received 8000 blows from a ram of from 1200 to 1400 pounds weight. He experienced some difficulty in preventing the heads from splitting, as the foundations were laid at 12 feet below the surface, and the piles cut off at 14 feet 1 inch; he imagined that the longitudinal fracture was not prolonged to this depth, being compressed by the natural ground.

The plan of this machine is shown as placed to drive the pile A. The cylinder is turned by the 10 feet wheel, which has roundles 18 inches apart on the circumference; the rope which coils round the cylinder passes over a wheel at the top of the machine, 4 feet in diameter, and is then attached to the ram, which weighed from 1200 to 1400 pounds; to release the ram when it had arrived at its proper height, a rope was attached to a hook, which, when pulled, released the ram.

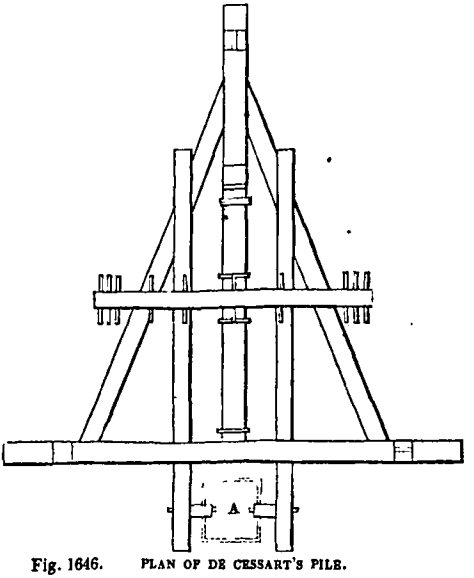


Fig. 1646. PLAN OF DE CESSART'S PILE.

Workmen, with the ordinary pile-engine, generally give 25 blows of the ram in a minute, each time raising three feet, consequently 75 feet per minute, after which they rest 2 minutes, giving the same velocity to the wheel, with the same number of men; that under consideration being 30 feet in circumference, it would make two turns and a half

per minute; the circumference of the cylinders winding up 3 feet of rope at each turn, it would raise the ram 7 feet 6 inches per minute, and the blow given to the pile would be equivalent to 200,000 pounds at least.

The pile-driving engine now in use is upon a very superior principle to those we have described; instead of having the ram of oak that was required to be hooped round in various directions to prevent its splitting, it is formed of cast-iron or bronze; the latter metal possessing greater elasticity is supposed to contribute to the driving of the pile; after the ram has been raised to its destined elevation by means of a crab or windlass, it is released by pulling a rope that opens the nippers attached at the top of it, when it falls with considerable weight on the top of the pile-head. The ram is maintained in its vertical position by a frame at the back.

Pile-driving Machine used at Montrose Harbour was attached to the steam-engine, and of ingenious construction. The ram weighed 12 cwt., and the clipper, with its slider, was of the ordinary kind, except that the upper part of the clipper had its extremities made of a sufficient length to allow the slider to rise 15 inches after the ram had been disengaged by the slips. The ram chain, which was shackled to the clipper, passed over one pulley at the top of the guides, to another part of the machine, by means of another pulley placed at the base of the guides.

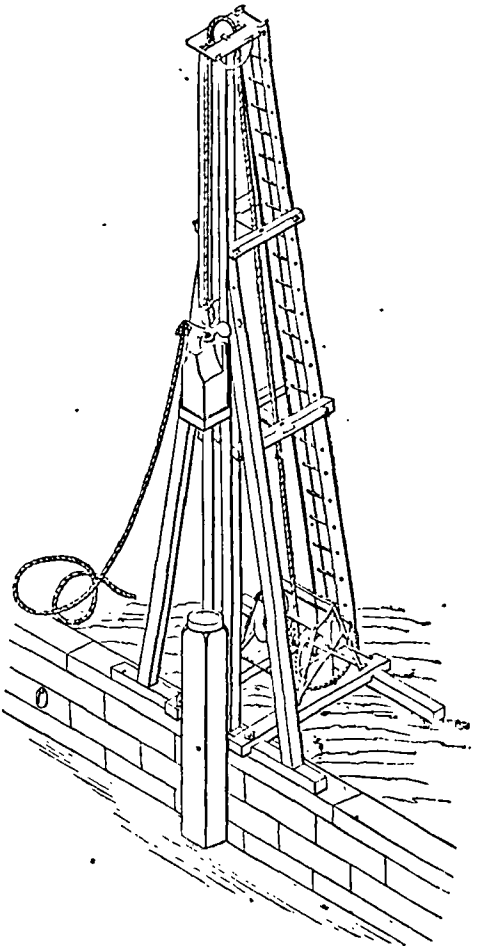


Fig. 1647. PILE-DRIVING ENGINE.

As the ram may be supposed to fall 16$\frac{1}{2}$ feet in a second, we may calculate its velocity in falling through any given height, as proportionate directly to the time of descent; the velocity acquired at the end of the first second is equal to 32$\frac{1}{6}$ feet per second, upon which principle the following table has been calculated, by which the force of the blow of any ram whatever

Fall of the Ram in Feet.	Time of the Descent in Seconds.	Force in Tons of a Ram weighing 1 Ton.	Fall of the Ram in Feet.	Time of the Descent in Seconds.	Force in Tons of a Ram weighing 1 Ton.	Fall of the Ram in Feet.	Time of the Descent in Seconds.	Force in Tons of a Ram weighing 1 Ton.	Fall of the Ram in Feet.	Time of the Descent in Seconds.	Force in Tons of a Ram weighing 1 Ton.
1	·25	8·0	11	·83	26·6	21	1·14	36·7	31	1·39	44·6
2	·35	11·3	12	·86	27·8	22	1·17	37·6	32	1·41	45·4
3	·43	13·9	13	·90	28·9	23	1·20	38·5	33	1·43	46·1
4	·50	16·0	14	·93	30·0	24	1·22	39·3	34	1·45	46·8
5	·56	17·6	15	·96	31·0	25	1·25	40·1	35	1·48	47·4
6	·61	19·6	16	1·00	32·1	26	1·27	40·9	36	1·50	48·1
7	·66	21·2	17	1·03	33·1	27	1·29	41·7	37	1·52	48·8
8	·70	22·7	18	1·05	34·0	28	1·32	42·4	38	1·54	49·4
9	·75	24·1	19	1·09	35·0	29	1·34	43·2	39	1·56	50·1
10	·79	25·3	20	1·11	35·9	30	1·37	43·9	40	1·58	50·7

may be ascertained, it being only necessary to multiply the force, in the last column, by the weight of the ram; thus a ram weighing 12 cwt. falling 20 feet, will have a force thus, $12 \times 35{\cdot}9 = 430{\cdot}8$ cwt.

Withdrawing Piles.—In harbours or tide rivers this is easily effected by attaching barges at low water to the heads of the piles, and as the tide rises, the pile must either be pulled out, or the barge pass under the water. In other cases Bramah's hydrostatic press has been used, or a framework of timber inclined so as to work a chain by means of a crab, to which blocks are attached, and draw them out: when piles have a slight hold, they may be drawn out by a long lever, acting upon a chain attached to the head of a pile: iron shod piles driven into gravel are sometimes difficult to withdraw, in consequence of the great oxidising of the metal; this principally occurs in sea water; when, therefore, they are to be withdrawn from such situations, it is advisable to omit the iron shoe, if at all possible.

In drawing out piles, the operation is considerably assisted by striking them with heavy blows near the head, in an oblique direction, by means of levers, and some ingenious

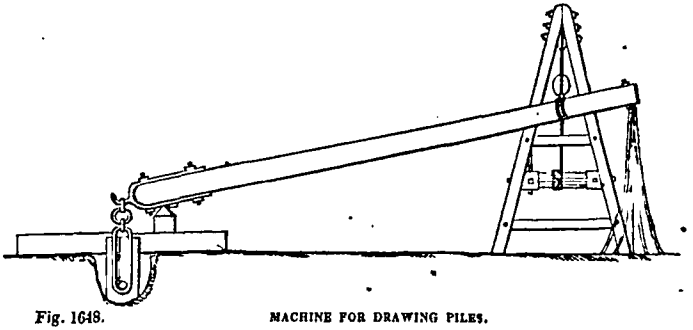


Fig. 1648. MACHINE FOR DRAWING PILES.

methods have been adopted: when the heads of the piles are out of the water, it is advisable to pierce a hole through them and pass a bolt, to which is attached the chain by which they are to be raised up. When the head is under the water, a square iron collar

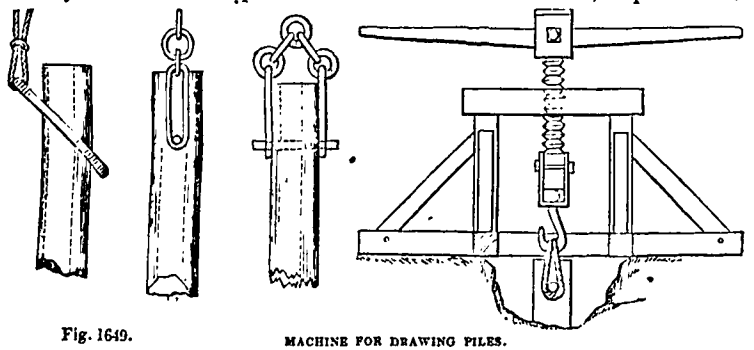


Fig. 1649. MACHINE FOR DRAWING PILES.

is passed over the pile, and, having a greater diameter than the latter, is placed obliquely; when the chain is tightened, the edges of the collar embrace the wood, and from the great pressure which takes place, all sliding off is prevented.

When the piles are rounded and shod with iron, they not only descend easier, but may be more readily detached: an improvement has been suggested upon the last machine, which consists in making the block attached to the screw rise as it is turned round, and the head of the pile being secured to each side of it by a link of iron, it can be loosened and drawn out with a more steady motion, all disposition to swerve from the perpendicular being prevented.

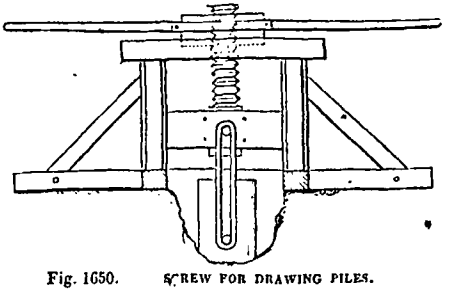


Fig. 1650. SCREW FOR DRAWING PILES.

Cutting off Piles.—This operation is by no means difficult when the foundations are

dry, but when under water a machine is requisite: this is composed of a horizontal frame formed by the three pieces A, A, A, 4 inches square, framed into two cross pieces B, B, and a vertical frame formed by the two uprights C, C, each about 4½ inches square. At the foot of these is placed the saw *l*, which is kept tightened by screwing the iron at the other extremity of the upright timbers, so as to bind or secure the blade. In order to give motion to the saw, a workman is placed to each of the handles at E, and alternately pushes them backwards and forwards in the direction A A, whilst another on the scaffold directs their labour, and holding a rope R, so places the saw that it at once puts a kerf into the head pile when required. This machine is usually mounted on wheels, and enabled to traverse the scaffold freely.

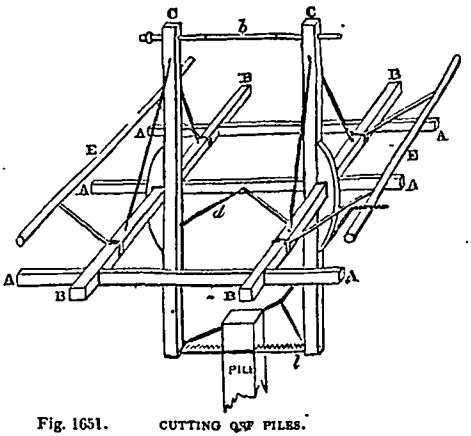


Fig. 1651. CUTTING OFF PILES.

At the bridge of Choisy such a machine was worked by a carpenter and six labourers, and who in 25 minutes sawed off a pile 10 to 12 inches diameter, placed at 3 feet 8 inches below the cross-pieces A, A, and thus cut off about 22 in a day of ten hours, the rest of the time being employed in altering the position of the machine and the scaffold. The saws cut with the most perfect correctness, when the frames which guide them slide in such a manner that the cross pieces A, A are allowed to remain in the same horizontal plane; but the upright pieces C, C cannot well be made more than 9 or 10 feet in length below the cross-pieces A, A; therefore, when it is necessary to cut piles at a greater depth, some other means must be resorted to.

Labelye, in building Westminster bridge, appears to have been the first who applied such a machine, in 1738, to cutting off piles. This engineer published a brief report in 1751 upon the various systems he adopted for the construction of this bridge, and it is to be regretted that he did not complete the account which he announced as preparing: many of Labelye's ingenious inventions have been copied without acknowledgment, and some even patented since his time; this is evident by a reference to the account preserved by the late Mr. Thomas Gayfere, who was senior apprentice to Mr. Jeff, the master mason employed at Westminster bridge.

For cutting off piles at more than 10 feet, or up to 15 feet below the water, the invention by Messrs. Voglie and Cesart at the bridge of Saumur may be considered ingenious, and was very successful: it was a modification of the one already described, and with four men to work the saw, and a fifth to adjust the saw against the pile, they were enabled to cut off a pile in five or six minutes, and could in the course of 12 hours cut off 22 piles, allowing for the moving and adjusting the machine.

De Cessart's Machine for cutting off the Heads of Piles under Water. — The machine was supported by a scaffolding, composed of three pieces of timber, 32 feet in length; each carried at its extremity a roller, 18 inches long and 8 inches in diameter, which were run on timber made perfectly smooth and level, placed equidistant along the length of the pier, and supported on the tops of piles.

The object of this machine was first to cut off the piles at a uniform height, and that the upper part of the pile should be cut truly level, that four men should work the saw with ease; that the pressure of the saw against the head of the pile should be regulated by one man, as the timber produced more or less resistance; that the operation should be performed with as much facility when the head of the pile was absolutely out of sight, as when it appeared above the water; that it should be practicable to cut another slice, if the first did not effectually level the pile; that the machine should embrace the head by grappling and taking a firm hold; that when necessary to clean or reset the saw blade, it should be done with facility, and that the small rolling scaffold should advance by degrees along the breadth of the pier, while the large scaffold carried it along to another row of piles.

For the first operation, the saw blade is drawn back by a regulator; the machine is raised 6 inches by the four perpendicular rods, which work with racks and pinions at the top, and is then advanced towards the pile; when it is lowered to the level of the intended cutting, an iron sounding rod serves as a gauge to mark this, and having established the level for the machine to work, the grapples are tightened by means of ropes, and the sawing is commenced: this is performed by four men, moving alternately the iron rods, which work in grooves at the top, and by means of other jointed rods give an oscillating motion,

resembling that of working a saw, to the bottom part of the machine, and which draws backwards and forwards by means of other connecting arms the saw which is to operate on the pile.

By a reference to the plan, we see the saw in its position after it has cut the head of the

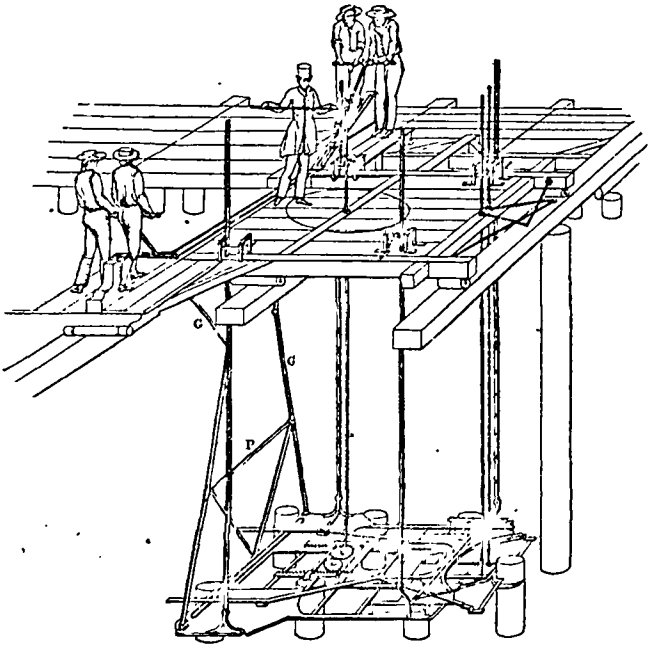


Fig. 1652.

pile partly through; at the back of the semicircle which holds it is a straight rod, which is made to slide along a straight groove; motion is given to this rod backwards and forwards

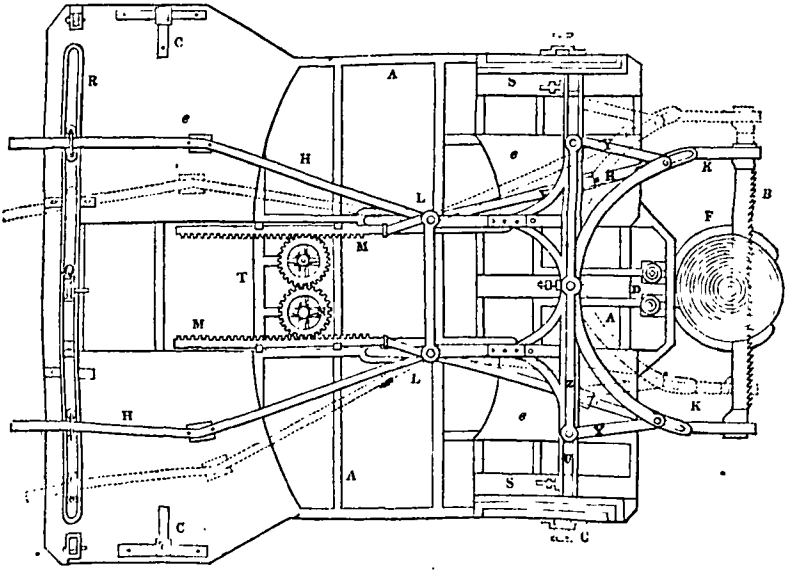


Fig. 1653.

in the groove, in such manner as the saw is required to move, and this motion constitutes the value of the machine.

A lever bent into three different directions, moving on a pivot at the first angle of its bending, and having a movable roller at the other, conveys the motion from the bascule or see-saw directly to the saw: the dotted lines show the extent of this motion one way, and the shaded part that of the other.

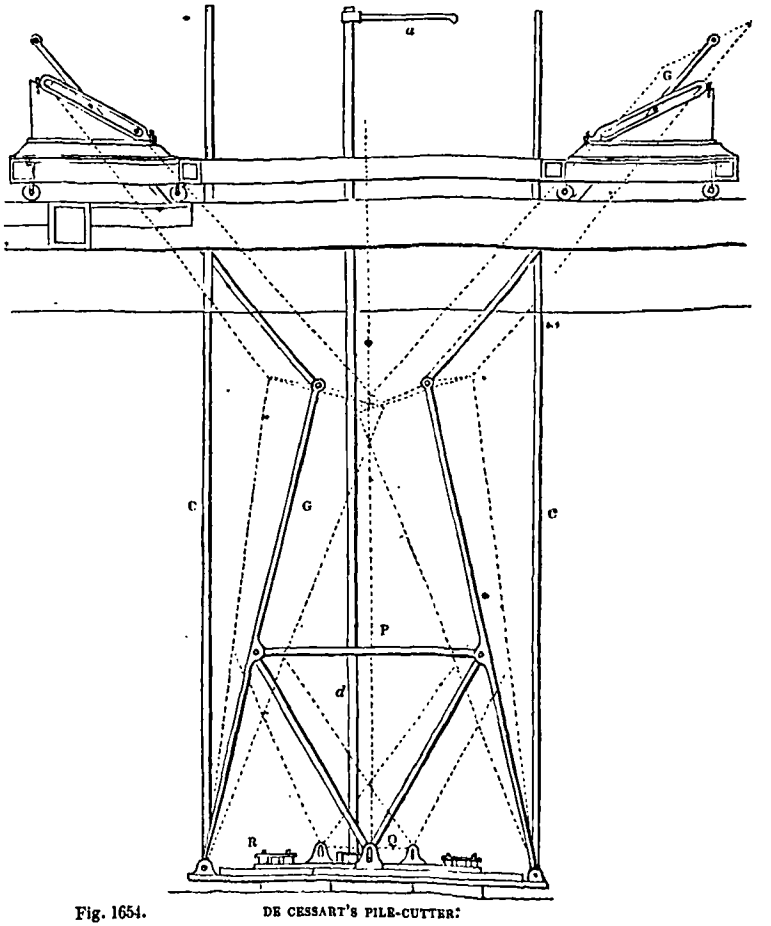


Fig. 1654. DE CESSART'S PILE-CUTTER.

In the section we see the various positions of the bascule or jointed rods when the sawing is in progress. The two wheels shown in the plan are worked by a rack and pinion by means of a rod coming from the top, by turning which any required pressure is given to the saw. The grapples, which clutch the head of the piles, are drawn back by means of levers worked at the top, and they are kept from turning by a rope attached to a ring fastened to one of the timbers of the upper platform: the time for cutting off the head of a pile is from three to four minutes.

This complicated machine performed its work with great precision, although several engineers continued to prefer that used by Labelye for cutting off the heads of the piles at Westminster Bridge: there can be no doubt that De Cessart's machine, from the variety of its movements and cost of construction, can only be adopted where very extensive works are to be executed; the more simple the saw is set, as long as it can be maintained in a truly level position, the better; for scaffolding, if not solidly put together, is very liable to produce by its change of form very great inequalities in the work performed. A saw mounted on an iron frame, and made to traverse upon two rails of the same material, would most correctly and efficiently execute the work, for there could be no difficulty by such an

arrangement to maintain a perfectly horizontal action for the machinery, in whatever situation it might be applied. In the "Traité complet de Mécanique appliquée aux Arts," by M. J. A. Borgnis, some other machines for this purpose are described.

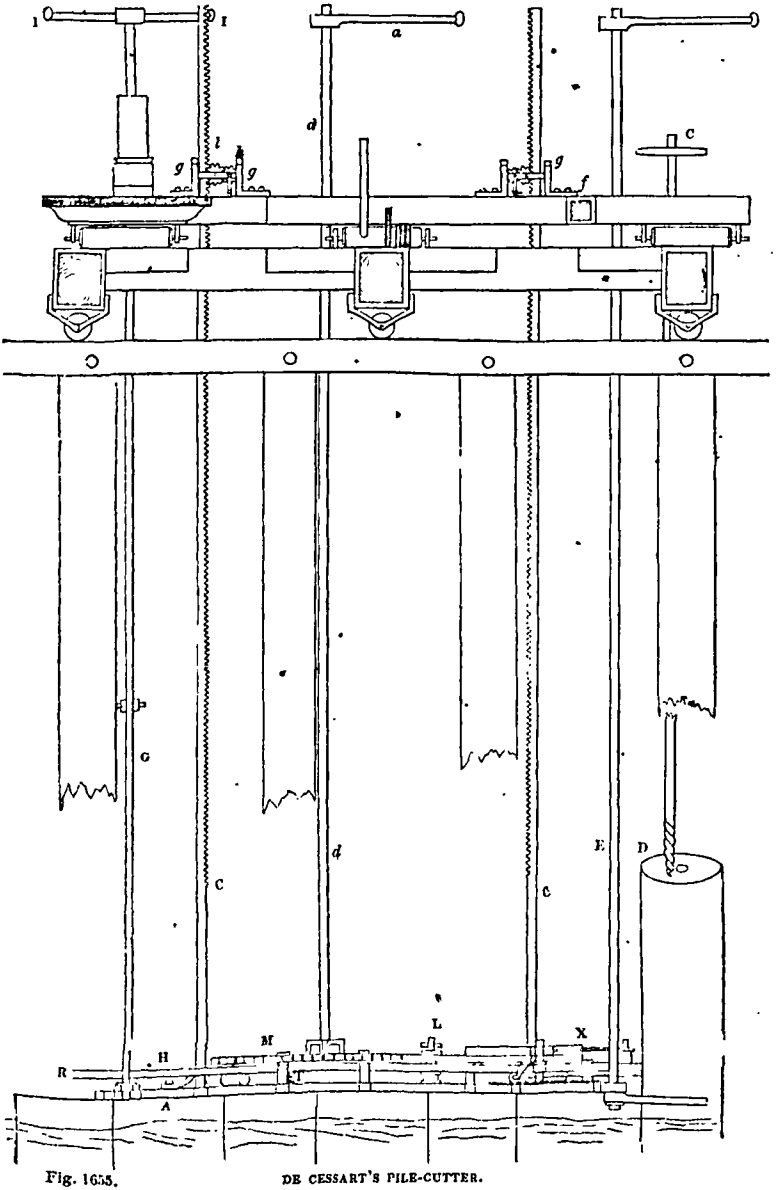


Fig. 1655. DE CESSART'S PILE-CUTTER.

Louis Alexander De Cessart, who executed the celebrated breakwater at the Port of Cherbourg, described in a former part of this work, published an account of most of his engineering works, among which is the detailed account of the dimensions and weight of the several parts of his machine for cutting off the heads of piles under water: as it is a curious document, and an example of the minute calculations entered into by French engineers for the construction of such kind of machinery, we have thought right to insert it; the dimensions are given in French feet, as the calculations in metres were not at that time established.

Details of De Cessart's Machine for cutting off the Heads of Piles, given in French Measures.

	Dimensions. In. Lines.	Cube quantity of iron. In. Lines.
First: Horizontal Movements.		
The semicircle, *k*, attached to the saw comprising the mâchoires, &c.		
Length	80 0	
Width	2 0	106 8
Thickness	0 8	
The two branches, Y.		
Length	30 0	
Width	1 6	22 6
Thickness	0 6	
Half circle, X.		
Length	48 0	
Width	1 6	30 0
Thickness	0 5	
2 branches of ditto.		
Length	30 0	
Width	1 6	18 9
Thickness	0 5	
Entretoise, Z, Z.		
Length	44 0	
Width	1 6	22 0
Thickness	0 4	
Channel, U.		
Length of two sides	122 0	
Width	0 9	68 7 6
Thickness	0 9	
Supports, S, S.		
The three wheels		50 0
Branches, M, M.		
Length	120 0	
Width	0 6	90 0
Thickness	0 6	
Buttress arches, V.		
Length	88 0	
Width	1 3	36 8
Thickness	0 4	
Irons, J, J.		
Length	16 0	
Width	1 3	6 8
Thickness	0 4	
2 entretoises, L, L, of the central movement.		
Length	48 0	
Width	1 6	24 0
Thickness	0 4	
Entretoises, T, T.		
Length	66 0	
Width	1 3	27 6
Thickness	0 3	
2 teethed-wheels and pinions.		
The two wheels		52 0
The two pinions		4 0
The two large levers, H, H.		
Length of the two	236 0	
Width	2 0	314 0
Thickness	0 8	
Total cubical content of the first movement		847 6 6
Weight in pounds of 16 oz., and taking 3 cube inches as equal to 1 pound, 291 lbs. 5 oz. 44/3 grains.		
Second: Vertical Movements.		
Equilateral triangle, P.		
Length	150 0	
Width	1 6	93 9
Thickness	0 5	
Entretien of the levers.		
Length	50 0	
Width	2 0	41 8
Thickness	0 5	
The cover of the angle		10 0
2 balances, G, G.		
Length together	192 0	
Width	2 0	192 0
Thickness	0 6	
The two covers		20 0
Carried forward		357 5

	Dimensions. In. Lines.	Cube quantity of iron. In. Lines.
Brought forward		357 5
2 iron arms, G, G, I.		
Length	198 0	
Width	1 6	148 6
Thickness	0 6	
Handle, I.		
Length	54 0	
Diameter	1 0	54 0
Total cube of second movement		559 11
Weight 186 lbs. 10 oz. 1 gr.		
Great iron frame, A A.		
Plates added together	826 0	
Width	3 6	722 9
Thickness	0 3	
Channels, R, for the regulation of the triangle		
Length of two sides	144 0	
Height	1 6	108 0
Thickness	0 6	
Iron plates cast for ditto.		
Length	72 0	
Width	2 3	40 6
Thickness	0 3	
Supports of the channel.		
The four		8 0
The two which sustain the balance		42 0
The two uprights		60 0
Pieces attached		14 0
2 channels, Q, Q, which occasion motion to the saw.		
Length of two sides	108 0	
Width	2 0	54 0
Thickness	0 3	
Iron supports of first.		
Length of the three bands	66 0	
Width	2 0	22 0
Thickness	0 2	
The guide which envelopes the grappling irons		
The round	24 0	
Width	2 0	16 0
Thickness	0 4	
Bands of iron, D, which maintain the plate against the pile.		
Length of the 2 bands	64 0	
Width	1 3	20 0
Thickness	0 3	
Total iron-work of the great plate		1107 3
Weight 369 lbs. 1 oz. 2/8 gr.		
Irons which change the movement on the plate.		
6 uprights, each 8 in. high, and the pieces attached		48 0
6 tail pieces		6 0
Channels.		
Length	44 0	
Height	1 3	13 9
Thickness	0 3	
Total		67 9
Weight 22 lbs. 9 oz. 2/9 gr.		
The griping pieces, F, F.		
Length	40 0	
Width	1 6	60 0
Thickness	1 0	
Uprights, E, E.		
Length	288 0	
Thickness	1 2	392 0
2 keys, *b*, *b*.		
Length	72 0	
Thickness	1 0	72 0
Total		524 0
Weight 174 lbs. 10 oz. 56/9 gr.		

	Dimensions. In. Lines.	Cube quantity of iron. In. Lines.
Uprights, C. C.		
Length	144 0	
Width	0 9	108 0
Thickness	1 0	
Side pieces for the spindles.		
Length	288 0	
Width	2 0	144 0
Thickness	0 3	
108 spindles		54 0
Stirrups at the end of the four uprights.		
Length	190 0	
Thickness	1 0	190 0
		496 0
Total for the uprights		1984 0
For the whole four		
Weight 661 lbs. 5 oz. $2\frac{6}{8}$ gr.		
The four crics, *f f*.		
Uprights	40 0	
Thickness	0 9	25 0
Width	0 10	
Four cross pieces.		
Length	29 0	16 3 9
Thickness	0 9	2 0
Pinion contains		8 0
Wheel		12 0
Toothed ditto		6 0
Axle		
Winch.		
Length	26 0	14 7 6
Thickness	0 9	
4 bolts.		
Length	40 0	40 0
Thickness	1 0	
		123 11 3
Total of one cric		495 9
For the four together		
Weight 165 lbs. 4 oz.		
Uprights, *d*, for regulating the movement.		
Length	168 0	262 6
Thicknesses	1 3	
Key, *a*, for regulating		
Length	36 0	36 0
Thickness	1 0	
Iron arms, I.		
Length of the 4 arms	180 0	101 3
Thickness	0 9	
Carried forward		399 9

	Dimensions. In. Lines.	Cube quantity of iron. In. Lines.
Brought forward		399 9
The four bands to hold the channels		48 0
		447 9
Platforms.		
Length of plates	160 0	
Thickness	1 6	60 0
Width	0 3	
Stirrup irons upon the scaffold.		
Length of the two	86 0	
Height	2 0	43 0
Thickness	0 3	
4 bolts and screws		28 0
5 ditto		14 0
Pivots		86 0
		628 9
Weight 209 lbs. 9 oz. $2\frac{1}{9}$ gr.		
Sounding rod is in length 12 feet		6 0
Total weight of the machine 2082 lbs. 7 oz. $6\frac{3}{9}$ gr., which at 15 sols per lb. amounts to 1561 livres 17 sous 3 den.		
	lbs. oz.	lbs.
Copper employed:—		
4 copper wheels which carry the horizontal levers of the saw	7 10	
6 copper wheels applied to the bras de force	5 0	
4 smaller ditto	3 0	
Rondelles or washers	17 8	
4 copper plates on which the large levers work		28
2 copper wheels upon the plate	1 11	
	34 13	28
Price of copper 1670 livres 1 sou 7 den.		
Price of scaffold for the machine 530 livres 18 sous 4 den.		
Making the total cost of the whole 2200 livres 19 sous 11 den.		

Steam Pile-driving Machine, as used in America for the construction of railways, deserves to be mentioned; it consists of two machines, similar to those used by hand, which are placed 6 feet apart from centre to centre; these are firmly bolted and secured to a strong horizontal framing, and further strengthened by two oblique ladders. The frame is 9 feet wide, and 28 feet long, carries at one end a locomotive boiler 11 feet in length, and 30 inches in diameter, which is calculated to bear 120 lbs. pressure per square inch, being worked only at two-thirds that amount, making 100 strokes per minute: in the centre of the framing, and on each side of the boiler, a pair of inclined cylinders, $5\frac{1}{2}$ inches bore, are placed; these have solid pistons which work without packing, with a 14-inch stroke, acting on right-angled cranks. The shaft centres are 1 foot 3 inches apart; the spur-wheel has 56 teeth, and pinion 19; the bevels 101 and 40 teeth; saw pulleys are 1 foot 9 inches and $10\frac{1}{2}$ inches in diameter: the ram is lifted from four to five times in a minute.

By this machine the piles are taken up by first securing the ram and then attaching the dogs to the head of the pile, and then, by means of a rope attached, and which passes upwards through the small guide pulleys and over the outer pulley E, passes downwards, and is coiled round the pulley F fixed on the shaft G, which, being made to revolve, raises the pile to its place between the pile-engines, and is then secured by the stay H, and the hoop or iron-work which guides it perpendicularly.

For driving the pile: the stop B being withdrawn from under the ram A, the ram is raised by a rope, which being secured by a staple on the top journal, passes down under the pulley I, then upwards over the pulley K, and again downwards to the drum L, upon which the rope is coiled; the drum is then placed on the shaft G, which is made to revolve by the spur-wheel N, working in the pinion O on the lower shaft P, which shaft revolves by the action of the two cranks Q, placed on the ends of the shaft P; the cranks are set at

right angles to each other, and are worked by the connecting rods R, attached to the piston rods, which are furnished with slide parallels. The slide valves of the piston are worked by the eccentric V on the end of the shaft P.

The steam is supplied by the pipe S from the boiler T, which receives its water from the cistern M by means of the pump W worked by the eccentric rod X fixed on the spur nave at Y, by the handle at Z. The supply of steam is regulated by the handle *a* acting on a valve in the steam pipe S.

The drum L consists of a fixed and loose cylinder, the latter revolving by the friction of the former, and is brought into or out of contact by the hand lever Y, which has a fulcrum attached to the standard.

The follower *f* is furnished with a pair of clippers, which takes hold of a staple fixed in the ram, and carries it to the top of the frame; and when the top of the tongs or clippers are pressed closer together by coming between the contracted cheeks *e*, *e*, the lower part opens and allows the ram to fall.

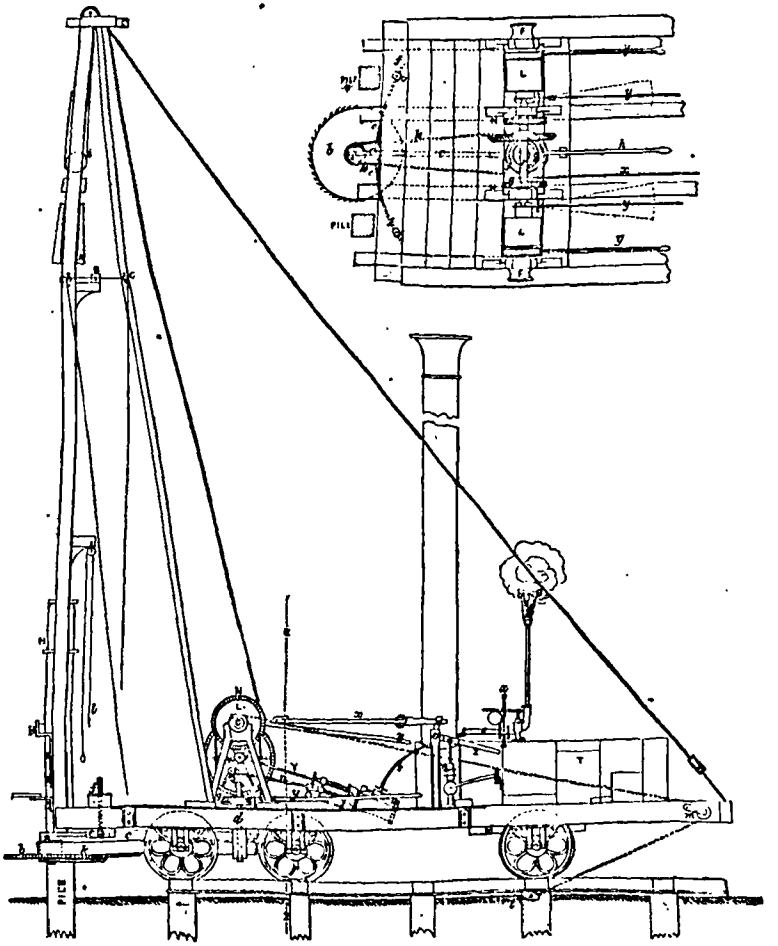


Fig. 1656. STEAM PILE-DRIVING MACHINE.

For drawing a pile, chain tackle is secured to the pile and passed over the top pulley to the drum L, and is then drawn by the drum of the apparatus turning round.

The saw apparatus has a saw 4 feet in diameter, which has teeth 3 inches apart, secured to the beam *c*, which works on the upright shaft *d* for a centre, and slides laterally on the iron arc *e*; when used the saw is adjusted to its proper height by the screw *f*, and a bar having a hook in one end, and fitting into a staple in the beam's end, is used to press the saw against the work; the bevel pinion *g* being raised into gear by the foot lever *h*, motion

is given to the pulley *i* and *j* and band *k*, which work the saw *b*, and which cut off the head of a pile in less than a minute.

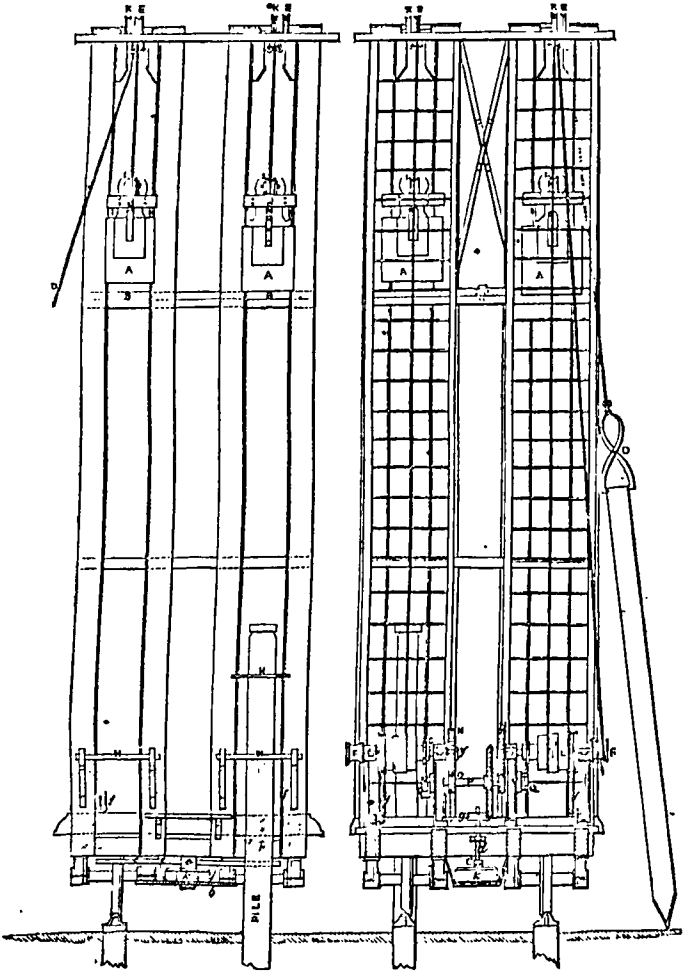


Fig. 1657. STEAM PILE-DRIVING MACHINE.

This machine has been very successfully employed on the railways in America, where the gauge was 6 feet from centre to centre; two piles were driven at the same time, with a ram weighing 16 cwt.; the number of men employed consisted of an engine tender, one man for throwing each apparatus in and out of gear, and one man to attend to each pile, making all together five men for driving two piles, which is about half the number of men required to drive two piles by the ordinary crab engines. By the machine the ram was lifted four or five times in a minute, and the cost of the whole engine and apparatus was about 700*l*.

CHAP. XV.

ON MECHANICAL AGENTS, OR THE FIRST MOVERS OF MACHINERY.

On the Strength of Men and Animals. — The animate moving powers most frequently employed are man, the horse, and the ox, the latter chiefly for agricultural labour: the form and construction of the human body seems applicable in a peculiar degree to become the first mover of machinery, particularly when aided by the skill and judgment which on most occasions are called forth to direct it. There are two methods of employing men and animals; one consists in making them walk with or without a load, the other in attaching them to a part of the machine, where they are required either to push or to draw, and hence communicate motion to the several parts.

By the term daily labour is meant the work performed during twenty-four hours, the effective duration of which is only a portion of that time, the remainder being employed in rest and taking meals. Animals of all kinds require that their work should be moderate and regular, and the machine they put into motion should never call forth more exertion than is natural for them: the limit of this action is indicated by the fatigue which the mover evinces, and which we may term the daily fatigue. Daniel Bernouilli imagined that the degree of fatigue was always proportionate to the action which produced it; so that whether the man was employed in walking, carrying a load, drawing or pushing, working at a windlass, or raising a weight, he always produced, with the same degree of fatigue, the same quantity of action, and consequently the same effect; and that the daily labour of a man may be estimated as raising 1,728,000 lbs. weight one foot high, or 60 pounds raised that height every second, when his daily labour was eight hours only.

Since these calculations were made, the celebrated Coulomb and Hachette have fully investigated the subject, and in our description of their experiments, we prefer retaining the French weights and measures, which cannot be so readily reduced to their proper quantities in English without fractional quantities: the kilogramme may be taken as equal to 2 lbs. 3 oz. 5 grs. avoirdupois, and the length of the metre, according to Captain Kater, is 39·37079 inches, and to M. Bailey, 39·3696786 inches.

The daily labour of man depends on the moving power, which results from the effort of which this mover is capable at each instant, and from the duration of effective work during a day of 24 hours, a deduction being made for rest, meals, &c. The moving power has for its measure a mass M, multiplied by a space h, which each point of the mass passes over in a unit of time: let us call T the time of effective work during a day; it is evident that the daily labour of man has for its expression the product of the three quantities, MhT. But keeping the product the same, can we vary the factors at pleasure? Daniel Bernouilli, who has discussed this question, thought that we could, from an equal degree of fatigue, obtain the same daily labour by changing the elements of this action. Desaguliers, differing from Coulomb, gives his opinion, that there is always for each man and each kind of labour to which he is habituated a maximum of action, which corresponds to the product of the three factors, MhT. This observation destroys the opinion of Daniel Bernouilli, who thought that a man or any other animated mover, in whatsoever manner he employed his strength, whether in walking, drawing, or by a winch, or on the cord of a pulley or any other machine, would produce with the same degree of fatigue the same quantity of action, and consequently the same effect.

Nevertheless, if, knowing the value of the factors of the greatest daily action of man, we give other values different from these, so that the product shall be constant, we shall be sure not to pass beyond the limits of the natural strength of man, and the effort of which he is capable, which will be conformable to the hypothesis of Daniel Bernouilli.

The expression of daily action of man or any other animated mover may be compared to that of a weight multiplied by the height to which this weight is raised: in effect, h being the space which a mass M goes over in a unit of time, the moving power is expressed by Mh; and because these masses are proportional to the weight, it has for its value the quantity Ph, P being the weight of the mass M, that is to say, that it is capable of elevating the mass P to a height h in a unit of time, and to the height Th in the time T: calling this height H, the daily labour of man has for its expression the product PH of the weight P elevated the height H.

Daniel Bernouilli estimates the daily labour of a rower as equal to 275 cube metres of water elevated one metre, and he supposes that this action is the product of 8 hours' effective labour out of the 24.

Sometimes the duration of effective work is confounded with the time which a man passes at the shop or the machine which he moves; nevertheless these two periods of time are very different; if a man walks and makes a halt of some minutes, we must regard the duration of the halts as a part of the time of rest, and must be added to the time of sleep and food. It is the same with all other work which requires an alternation of action and rest, only considering that the duration of action diminishes at the same time as the moving power or the intensity of the momentary effort of the mover augments. It has been observed that a man or horse developes the power of which he is capable, in a day of 24 hours, in a very variable time, which is at least one hour, sometimes 1½ hours, and generally 8 to 12 hours.

When we can regulate the two elements of daily labour, the moving power and the time of effective labour, it would be desirous that we should find the value of those elements which determine the greatest effect of daily labour: by multiplying the experiments on a great number of men, and for several years in succession, we shall ascertain exactly the various daily labours, or at least the limits of these actions, having a regard at the same time to the natural strength of the individual, to climate, and all the circumstances which modify this force.

On the Velocity with which Man moves.—This depends on various circumstances, for when walking on a plain without a load, he moves at the rate of 13 or 16 decimetres per second: according to the observations made by Bouvard during a review of the troops at the Champ de Mars at Paris, 251½ metres were passed over in 33 seconds, which is at the rate of 7·7 metres per second. Soldiers when marching at ordinary time take 76 paces per second, and pass over 50 metres: when this pace is accelerated 100 paces in the same time, and they pass over 66 metres: when marching quick, 230 paces are made per second, and 130 metres are passed over. This gives for the ordinary and accelerated time 0·66 metres, or 2 metres for 3 paces; and in 1 second of time $\frac{50}{60}$ of a metre at ordinary time, $\frac{66}{60}$ when accelerated, and $\frac{130}{60}$ when at quick time. When a man is travelling without a load, and on level ground, he performs from 40 to 50 kilometres per day during the 8 or 10 hours he is engaged out of the 24. The French soldier carries a load equal to 18$\frac{7}{10}$ kilogrammes in time of peace, and 25½ in time of war.

Daily Labour of a Man has for its measure the resistance expressed in weight, multiplied by the road; and when he walks over a level road, the resistance he overcomes at each instant is unknown: when he mounts a staircase, at each step he elevates the weight of his body; the height of the riser and his weight we consider as the measure of resistance; so that the daily labour has for its measure the product of the weight of the body, multiplied by the height to which it is elevated during the effective labour of one day.

According to an experiment made at the Peak of Teneriffe, which is 3780 metres above the level of the sea, 8 men loaded with 7 or 8 kilogrammes, who accompanied Borda, were elevated the first day 7½ hours' effective work, to the height of 2923 metres. Supposing the resistance equal to the weight of a man, which is 70 kilogrammes, augmented by a load of 7 kilogrammes, we have for the measurement of the action in a day of each of the 8 men 225 cube metres of water elevated 1 metre; the ramp being 20 kilometres, the fall will be 14 centimetres per metre. The man who mounts with two motions, one horizontal, and the other vertical, each of which has a separate resistance, the sum of them must be taken, which we suppose equal to 77 kilogrammes. In this experiment the height to which a man is elevated in a day is not that to which he elevates himself by walking moderately, for Coulomb offered to labourers the price of a day's ordinary work to mount 18 times without burden on a ramp of 150 metres height, or, what is the same thing, once to a height of 2700, and they constantly refused.

It is, therefore, probable that a man travelling in a mountainous country without a load, and at a gentle elevation, would terminate his journey when he was elevated 2 kilometres, after marching 8 hours, whilst he could at the same time, and without fatiguing himself, move 40 or 50 kilometres on a level road: by only counting on a march the effort necessary to elevate at each pace the entire body above the surface of the earth, and supposing this elevation to be 3 centimetres, the total elevation will be the number of steps multiplied by 3 centimetres; or, the number of paces is the quotient of the number of metres gone over in a day, multiplied by the length of the steps, or 40000 metres divided by 0·66, which is 66666; multiply this by 0·3; the product is nearly 2000 metres, equal to the height of the ramp. The act of walking consists in gliding over the earth, and elevating the centre of gravity as little as possible; this first effect produced, he must also give a horizontal velocity; this second effort of walking requires an effort which is added to that which precedes for the elevation of the body, but which is evidently much less. We know no experiment which determines the relation of these two efforts. Multiplying 2 kilometres by the weight of the man, 70 kilogrammes, we have for the measurement of his daily labour during the length of his march in mountainous countries 140 units, each unit being a cube metre of water elevated 1 metre.

If a man mounts when loaded, this action will diminish, as we shall see by the following experiment of Coulomb's: he observed that a man may carry in a day six loads of wood to a height of 12 metres, each being 734 kilogrammes, carried in 11 journeys, or the 6 loads in 6½ hours. Thus the man made 66 journeys, and elevated a weight of 6 × 734 kilogrammes of wood to a height of 12 metres, or 53 cube metres of water to a height of 1 metre. He elevated himself 66 times to a height of 12 metres, and this work is expressed by the number 56, the product of three numbers, 70 kilogrammes, 12 metres, and 66 journeys. Adding this number to the preceding, we have for the measurement of the daily labour of a man who mounts loaded, the number 109, less than the 140 found before.

In the experiment made on the wood porter, each burden of $\frac{65}{67}$, or 67 kilogrammes, were mounted in $1\frac{1}{10}$ minute, so that the duration of the principal work in a day of 24 hours was 1 hour 12 minutes; this work was paid at the rate of 1 franc per load of wood mounted 12 metres. The time which elapsed between the two consecutive mountings was about breathing time; it was employed in loading the crochets, log by log, in descending the stairs, &c.; it appears that this method of dividing into short intervals of work and rest the labour of men carrying great burdens, is that which agrees best with the animal economy, and that men prefer a very fatiguing action of some moments, followed by the time necessary for rest, to a less powerful exercise, but more continuous and of longer duration.

The result of the experiment cited by Coulomb differs very little from that which Gueniveau relates in his Essay on Machines; this engineer observed the workmen who mounted from coal mines by very steep and inconvenient stairs; their load varied from 35 to 40 kilogrammes, and the daily effect was 42 to 50 kilogrammes elevated 1 kilometre: taking the weight of the man into consideration, 70 kilogrammes, the daily labour would vary from 112 to 120 dynamic units.

Loads of equal weight fatigue much less in proportion as they are distributed equally on all parts of the body; a man carrying a weight equal to his own, and mounting a ladder of a given length, would fatigue himself more than if he mounted without a load by the same ladder to double the height: although in these two cases he would produce the same dynamic effect, the second height would produce much greater fatigue than the first.

Coulomb often proposed to different porters to carry furniture from one house to another at a distance of 2 kilometres on a horizontal road, loading themselves at each journey with a weight of 58 kilogrammes; they all told him that they could only make 6 journeys per day, at 1 franc 50 cents per journey; they added that they could not sustain a similar fatigue two days in succession.

Several hawkers were interrogated as to what was the greatest weight they could carry in their journeys, and how far they could go with this weight; the strongest of them answered that, loaded with 44 kilometres, they could not proceed farther than 18 to 20 kilometres in a day.

We conclude from these different experiments that the action of walking with or without a load on a plain, or in a mountainous country, is bounded by limits which depend on the development of the vital forces, which are very variable, and have no absolute measure.

The resistance surmounted at each instant by an animated mover is only to be determined and measured when this resistance is without the mover: in this case the mover exercises on a point which resists a pressure equivalent to that of a weight. The man who walks either with or without a load exercises two kinds of pressure, one on the ground, the other on himself; the latter is not known; whence it follows that there is no absolute measure of the daily labour of a man walking, and it differs essentially from those labours in which we only consider the pressure exercised on an exterior object: of whatsoever kind these labours may be, they are only to be compared to those when they produce the same degree of fatigue, and when animated movers can sustain the daily labour which is an object of comparison, without injuring their physical constitution.

Of the daily Labour of a Man moving a Load on a Wheelbarrow, or other small Carriage.—Pascal was, it is said, the inventor of the wheelbarrow: this machine is a case longer than it is wide, attached to a frame, whose arms are longer on one side than on the other. The shortest side carries the gudgeons of the axle of a small wheel. The load is placed in the case, and the man charged with transporting it seizes the handles of the barrow at about 15 decimetres from the spindle. The total weight of the barrow is about 30 kilogrammes, and it is loaded with 70 kilogrammes when used for moving earth. Vauban, whose name recals the epoch of the greatest earthworks, observed that a man in his daily labour can make 500 journeys of 29 metres each, with a barrow loaded with 70 kilogrammes: to compare this effect with that which we obtain from porters loaded with crochets, we shall estimate the daily labour of the latter by the weight transported, and the distance passed over. Thus, we have for the effect of the hawkers in a day 44 kilogrammes × 20 kilometres, and for that of the workmen with a barrow 70 kilogrammes × 14·5 kilometres. These two effects are in the relation of 880 to 1015; thus, if we only regard the weight of the

masses transported, the wheelbarrow as a means of transport is preferable to the crochet; but it must be remarked that the volume of the masses increases the difficulty of transport, and it is probable that hawkers have more fatigue than men at the wheelbarrow.

Coulomb found that to sustain a loaded barrow by means of a dynamometer, fixed at the point the man holds by, supported a weight of 18 to 20 kilogrammes, and that the force necessary to drive the barrow loaded on dry firm ground was 2 to 3 kilogrammes. This weight measures the continuous effort of a man pushing the barrow; multiply this effort by the space, 14 kilometres, which he goes over in 500 journeys, and we have 28 to 42 great dynamic units for the measure of the efforts which produce the useful daily effect.

In mines sledges are sometimes used, which slide over an unequal and argillaceous soil; those observed by Gueniveau were drawn by a single man, and loaded with 90 kilogrammes of coal. The space passed over was 290 metres; the workman made 24 journeys in the day, and returned with the sledge empty, which gives for the effect in a day 90 kilogrammes transported 6960 metres, or 626 kilogrammes transported 1 kilometre, an effect less than that produced by the hawkers, and which was estimated in the preceding article at 880.

The small waggons used in mines, says Gueniveau, are supported on 4 wheels, and drawn by men distributed along the road at a distance of 100 metres: the waggon rolls on planks, and the daily effect of each man is 900 to 1000 kilogrammes transported 1 kilometre: when there are inequalities in the floor of the gallery, which are otherwise supposed horizontal, this effect is reduced to 600 kilogrammes transported to the same distance.

Of Men acting on Pulleys. — According to Coulomb, ordinary rams used for driving piles weigh 350 to 450 kilogrammes: a cord passing over a pulley sustains the ram on one side; at the other extremity of the cord different strings are attached, which men seize with their hands: when the ram strikes the piles, the men hold the cord about the height of their heads; bending at the same time as they apply an effort to the cord, they elevate the ram about 11 decimetres. They make nearly 20 strokes in a minute, and three or four minutes in succession, after which they rest nearly as long as they have worked; notwithstanding this repose they are obliged to be relieved every hour. Men cannot perform more than three hours' effective work in a day; the remainder of the time is occupied in placing and displacing the machines, dressing the piles, &c.; these works require slight effort, and afford time for regaining the strength. In this experiment the number of men applied to the machine is such that each man lifts 19 kilogrammes of the ram.

According to these data the daily action has for its measure the product of these three numbers, 11 decimetres, 19 kilogrammes, and the number of strokes given in three hours' effective work, at the rate of 20 per minute, which gives 75 dynamic units.

Coulomb has followed, fifteen months in succession, the labour of coining money at Paris. These pieces are struck by means of a ram weighing 38 kilogrammes; two men are employed, and consequently each elevated a weight of 19 kilogrammes: the elevation was 4 decimetres, and in one day 5200 pieces were struck, or, what is the same thing, the ram was elevated 5200 times in a day, which gives for the daily labour 39¼ dynamic units. In the preceding example, we have for the measure of this action 75; but it must be remarked that the same men work in the Mint 15 hours in succession, instead of which, when driving piles, the men pass from one kind of labour to another when they are fatigued.

An Experiment made at the Bridge of the Military School, under the Direction of M. Lamandé, Chief Engineer of Bridges. — For driving piles a ram was used weighing 587 kilogrammes, worked by 38 men; at each blow they elevated the ram 1·45 metre; after 30 blows they rested a time equal to that of the blows. They gave 12 series of blows in an hour, or 12 strokes per minute, effective and continuous work: supposing they could have sustained this work 6 hours a day at 12 series of blows an hour, the daily labour of each man would be the product of $\frac{587}{38}$, or 15·44 kilogrammes multiplied by 1·45 metres, and by 72 series, 30 strokes, which gives 48 dynamic units.

Coulomb says, "I have drawn water from a well 37 metres deep: a man worked by means of a double bucket, attached to the extremity of a cord working over a pulley; he drew up the first day 125 buckets; the second 119, at 25 centimes per 10 buckets: the mean effort, measured by a dynamometer, was 16 kilogrammes. We have the daily labour by multiplying the three numbers 16 kilogrammes, 37 metres, and 120, the number of buckets mounted in a day, the product is 71 great dynamic units.

Men acting on Winches. — According to Coulomb the pressure of a man in a continuous labour exercised on the handle of a winch is about 7 kilogrammes; most frequently the swiftness of the rotation of the handle is such, that each point describes in a minute 20 to 22 circles, each of 23 decimetres. The duration of effective work in a day is about 6 hours: in this hypothesis the daily labour is the product of three numbers, 7 kilogrammes, 6 × 60 minutes, 20 × 2·3 metres, or 116 great dynamic units.

Of a Man pushing as he walks, or drawing harnessed. Mill-walk in the Wells of Bicêtre.—The Bicêtre contains three establishments: the hospital for the mad people, the prison, and the infirmary. Those who are least diseased, mostly the epilectic patients, receive a small remuneration for drawing water from a well; 72 men are designed for this service; 24 only work at once, for 1 hour 20 minutes in succession, and are replaced by others for the same time.

The mill-walk is in an octagon tower, whose opposite faces are 11·69 metres distant; the centres of the horizontal bars which the men push before them while walking are on a circle 5·2 metres radius; these bars are directed towards the axis of the mill; 16 men walk without the walk and 8 within; there are 8 couples of men, and each couple push the same bar; the distance between two men of the same couple is 8 decimetres; the height of the bars above the ground is 9 decimetres; the distance between two consecutive bars is 1·3 metres; each man is placed between two bars, which he pushes alternately before him, according as the wheel is to turn in one direction or the other.

The well is 52 metres deep from the surface of the water to the crochet which empties the buckets; the interior diameter is 4·872 metres; the water constantly stands at 4·872 metres from the bottom.

A vast reservoir of a square form, well vaulted, contains more than 1000 cube metres of water; the vault is supported by 16 columns, which serve as piers to 9 elliptical arches: this reservoir, the tower, and the well, were executed in 1733-4, from the designs of Boffrand, engineer of bridges and roads.

Of the Swiftness of Men pushing the Bars of the Mill.—The men make 8½ turns in 5 minutes, the time necessary to elevate a bucket from the surface of the water to the bank, taking the mean walk of 24 men as a circle of 10·4 metres diameter; the 8½ turns correspond to 278 metres, which gives 0·92 metre for the velocity in 1″.

Useful Effect of the moving Power.—In a relay of 1 h. 20′, or 16 times 5′, they raise 16 buckets; a bucket contains 700 litres, weighing 700 kilogrammes: thus the useful effect of 24 men is 700 kilogrammes × 16 × the height to which the water is elevated, or 52 metres, and for each man this number divided by 24, that is to say, 25 great dynamic units of a cube metre of water elevated 1 metre. The remuneration of this work is 8 centimes a man.

The waters of Arcueil, and other sources more elevated than the Bicêtre, bring together six months in the year a considerable quantity of water, and then four or six relays suffice to draw from the well the water necessary for the service of the establishment; but in summer the natural sources fail, and each labourer makes four relays, which causes his daily labour to be 100 dynamic units; it is only one-half during six months of the year, so that the mean daily labour is 75. The quantity of water drawn in 12 relays is expressed by the product of the three numbers 700 litres × 16 × 12, or 134400 litres. The population of the Bicêtre being about 3000, we have nearly 45 litres for each individual; it is generally supposed that 20 litres for each person would suffice for the wants of a great town; on account of the baths watering the gardens of the Bicêtre, the consumption is more than double.

The Force developed by the Mover.—It was intended to measure, by means of a spring, the mean pressure of men on the bars of the mill at the Bicêtre; but this project was abandoned on account of the great inequality of force in the individuals, more or less weakened by age and infirmity. The resistance to be overcome is unequal, but it is at its maximum when the buckets rise from the water, whilst the other begins to descend; the cables carrying the buckets are 2 decimetres in circumference; each passes over a pulley 1·3 metres in diameter, and coils round the drum of the machine, whose diameter is 1·9 metres; the part of the cable comprised between the pulley and the level of the water in the well weighs 250 kilogrammes. The resistance which acts tangentially to the drum will be 700 kilogrammes, the weight of a full pail of water added to the weight of the cable when the bucket begins to ascend, and subtracted from that of the cable when the bucket is at the height of the hook, which is inclined to empty it; thus the resistance varies from 850 to 550 kilogrammes. The buckets weigh, when full, iron and wood comprised, 600 kilogrammes, but one always equalises the other, and we must only count it as inertia: the distance of the axle of the machine to the vertical axis of the well is about 13 metres: whatever is the weight of the cable, the mean resistance being 700 kilogrammes, acting on a radius of 3 feet, the power producing the equilibrium will be at the extremity of the radius 16½ feet; taking $\frac{3}{16}$ of 700 kilogrammes, gives 127 kilogrammes for the total pressure on the bars. If we subtract the inertia and friction of the cable on the pulleys and on the drum, the mean pressure of 24 men working the machine will be $\frac{127}{24}$ kilogrammes, or 5 metres 3 kilogs. On account of the inertia, friction of the ropes on the pulleys and drum, we suppose the mean pressure to be 7 kilogrammes, so that the relation of the useful effect of the force developed to produce it is that of 5·3 to 7, or 0·8 to 1; that is to say, a fifth only of the force developed will be employed to overcome friction

and inertia, which is probably the case in this machine, where the construction is simple and carefully executed.

The Horse considered as a Mover. Of his Swiftness. — The greatest swiftness of a horse in a course of 7 or 8 minutes is 12 to 15 metres per second. Bouvard observed that in the Champ de Mars at Paris, a horse mounted by a cavalier on a smooth road winding in the form of the figure of an eight, went over 2575 metres in 3′ 31″, or 211″. In the Newmarket races a horse has gone over 6784 metres in 7′ 30″: a horse harnessed in a cart has gone over 1478 metres in 2′ 13″ on a road in the form of an eight, in the Champ de Mars.

These three experiments gave for the swiftness of the horse in 1″,

1st experiment	- - -	12·21 metres.
2 —	- - -	15· —
3 —	- - -	11·11 —

We are assured that a harrier is capable of following the best English horse, and that the reindeer attached to a sledge runs at the rate of 8 metres per second.

Cavalry makes in a minute,

at the common pace - -	120 steps,	and goes over	- 100 metres.
trot - - - -	180 —	—	- 200 —
gallop - - - -	200 —	—	- 320 —

which gives for the ordinary length of a horse's step 0·83 metres, for the velocity corresponding to this pace 1·66 metres per second; for the velocity at a trot 3·3 metres; and at a gallop 5·3.

It has been remarked that the pace of a man more or less accelerated is always nearly of the same length: the inequality of a horse's step proves that he throws out his legs in running, and clears a space which must be added to his ordinary step. Bose saw in N. America savages who leapt while walking, and he assures us that this manner of proceeding was very favourable for an accelerated and continuous velocity, and also fatigues less than any other.

A good horse loaded with about 80 kilogrammes, including the weight of the rider, can daily go over 40 kilometres (25 miles English) in 7 or 8 hours, which gives from 1·4 metres to 1·5 metres per second. The weight of a horse of mean strength is 225 to 250 kilogrammes.

The tractive Power and Load of a Horse.—In contracts for carting, we generally calculate the load of the carts at 700 to 750 kilogrammes to a horse, without comprising the weight of the cart: the tractive power of a good waggon horse is 140 kilogrammes; a team goes over on a good horizontal road 38 to 40 kilometres in 8 or 9 hours; at 40 kilometres in 8 hours the velocity is 1·4 metres in a second.

Horses attached to diligences going at a trot, and making a post or 8 kilometres in an hour, go over daily 34 to 38 kilometres: the tractive power of each is about 90 kilogrammes; their velocity is 2·2 metres in 1″.

The daily action of the horse of a waggon being expressed by the product of two numbers, 90 kilogrammes and 38 kilometres, these two actions are in the relation of 5600 to 3420, or 163 to 100. These experiments give 100 kilogrammes as the mean tractive power of horses.

Of the Strength of the Horse taken as a dynamic Unit. — The constructors of steam-engines estimate the power of these machines in dynamic units, each of which measures the strength of a horse when harnessed. Let us suppose that a horse is capable of moving a mass of 140 pounds with a velocity of 200 feet in a minute: this dynamic effect is 28000 pounds elevated 1 foot, or 4149 kilogrammes 1 metre; according to this definition, the strength of a horse working 24 hours continuously is equivalent to 5974 units, each the weight of 1 cube metre of water elevated 1 metre; or, 5974 × 2208 pounds avoirdupois raised 3·281 feet English.

Machine of Mr. Gonin Dyer, Rue Blanche Castile, Isle St. Louis. — This machine has one horse, which works 5 or 6 hours a day in three relays; in 1 hour he lifts by means of a pump 28 muids of water, each muid being 268 litres 13 metres high, or 97½ cube metres to a height of 1 metre, which gives for the daily labour of 6 hours in the 24, 585 metres of water elevated 1 metre.

Machine near Paris over a Plaster Quarry. — This machine has one horse which works 12 hours a day; the effect is to elevate by means of a drum 96 casks of plaster from the bottom of the quarry to a height of 23·4 metres; each cask weighs about 375 kilogrammes, and the weight of the plaster elevated in a day is equal to 36 cube metres of water, which gives 842 dynamic units for the daily action.

The horse harnessed to the extremity of a lever 3·575 metres long goes over in a minute a circle of 22·4 metres, in a second an arc of 37 centimetres. and in 10 hours of labour 13·4 kilometres.

The cask is elevated in 7½ minutes; at each ascension the horse stops to change the direction of his rotatory movement: supposing the duration of effective labour to be 10

hours, and knowing by the dynamometer that the traction is 100 kilogrammes, we have for the force developed in a minute 100 kilogrammes multiplied by 23·4 metres, or 23·4 dynamic units, and in 12 hours 1684 great dynamic units, which have produced the useful effect expressed by the number 842, half the preceding. By only comparing the force developed in a minute, and the corresponding useful effect, we have for its measurement the weight of a tub, 375 kilogrammes, multiplied by the height, 23·4 metres, which product must be divided by 7·5, although the barrel is only elevated in 7½ minutes. The force being 2·34, the useful effect is half, or 1·17.

Machine established in the Brewhouse called Bon Pasteur, 80 Rue Mouffetard. — Three horses harnessed to the same machine elevate by means of a pump 155 muids of water to a height of 132 feet, and the duration of work corresponding to this effect varies between 4 and 5 hours, according as the pistons of the pump are in good or bad order: this action of 3 horses is equivalent to 1784 great units, which gives 593 units for each horse.

The diameter of the circle described by the horses is 6 metres, and they make 13 turns in 5′; each turn is 19 metres, which gives about 0·8 metres as the swiftness per second, the length of the ordinary step of a horse. The traction of each horse being 100 kilogrammes, the force developed in 4 hours is 1185, almost double the number of the useful action 595. The machine communicates motion to the pumps, or to a mill for grinding malt: the horses grind in an hour 5 sacks of malt weighing 100 kilogrammes each.

Machine established at the Hotel des Invalides to elevate Water from a Well by a system of Pumps. — Eight horses perform the service from 6 in the morning to 6 at night: each horse works 6 hours, in two relays of 3 hours each, separated by a rest of the same duration: 4 horses are harnessed to the machine at once.

There are two reservoirs, one 6·02 metres high from the ground, the other 16·5 metres. The distance from the ground to the level of the water in the well is 19·16 metres, so that the height to which the water must be elevated in the first reservoir, which is the largest, is 25·2 metres, the height for the small reservoir 35·6 metres. The quantity elevated in 12 hours in the two reservoirs are respectively 165 and 35 cube metres of water.

The useful effect corresponding to the daily action of the 8 horses will be expressed by $165 \times 25{\cdot}2 + 35 \times 35{\cdot}6$, or 5404 dynamic units, which gives for each day 675 units in 6 hours of work, and 1·87 in a minute for each horse.

The radius of the machine is 4 metres; the horse makes 2½ turns per minute, and goes over 63 metres, which gives 1·2 metres for his swiftness in 1″. The mean draught of 4 harnessed horses, as observed by the dynamometer, is 130 kilogrammes for each, which gives for the force developed in 12 hours four times 130 kilogrammes × 63 metres × 60′ × 12 hours, or 23586 dynamic units.

By comparing this number to the useful effect, expressed by 5404 dynamic units, we see that this effect is only $\frac{23}{100}$ of the force developed.

Other Observations on the daily Labour of a Horse. — Armallet, engineer of bridges and roads, describes a machine with pulleys at work in the coal mines at Blanzy, near Creusot, Canal du Charolais, moved by two horses, which elevated in 9 minutes coal weighing 450 kilogrammes to the height of 130 metres. He added that the effective labour was 8 hours out of the 24: according to these statements, the daily labour will be expressed by 1560 great units. I agree to the first part of the observation, but has the second, relative to the duration of effective labour, been made several months in succession? It is allowable to doubt this, when we arrive at a result double that which a great number of experiments give.

Other Experiments on Transport by Water. — Perronet relates an experiment made on the canal of Loing. A single man drew a boat loaded with 100 milliers, and in 10 days he went over a space of 110 kilometres, so that his daily labour was 100 milliers transported 11 kilometres. Supposing the draught of a man 10 kilogrammes, the work would be expressed by 110 dynamic units.

He has further observed that a single horse draws a boat of 300 milliers, and goes over 8 kilometres in a day: admitting that the draught is 100 kilogrammes, the labour of the horse will be expressed by 800 units: it is very probable that the forces developed are in fact in the relation of 100 to 800; nevertheless the useful effect produced in a day are only in the relation of 11 to 24, or 1 to 2·2.

It would be important to repeat these experiments, and to measure the draught corresponding to the velocity of men and horses, having relation to the form and swiftness of the boat, and to the greater or less resistance of the fluid.

Summary of the Experiments on the daily Labour of Man; the dynamic unit being the weight of a cube metre of water elevated to the height of 1 metre, or 2208 lbs. avoirdupois raised 3·281 English feet.

	Dynamic units
We have, for a man walking 7½ hours on a slope of 14 centimetres in a metre with a burthen of 7 or 8 kilogrammes - - -	225
A man walking in a mountainous country without a load - -	140

	Dynamic units.
A man carrying wood up a ladder, his own weight being 56, and that of his load 53	109
A coal porter on a ladder, his own weight being taken into account	112 to 120
A man applying his strength to a rope over a pulley to raise a ram	75
The same—another experiment	40
The same—another experiment	48
A man drawing water from a well by means of a cord	71
A man working the handle of a winch	116
A man drawing a boat with traces	110

A unit of transport being the weight of a cube metre of water transported 1 metre on a level road, we have—

	Dynamic units.
A man travelling over a level plain, his own weight being 70 kilogrammes × 50 kilometres	3500
A soldier loaded with 20 to 25 kilogrammes, and marching 20 kilometres a day	1800 to 1900
A Roman soldier making a forced march of 40 kilometres a day	4400 to 4800
Hawkers with crochets, the weight of the man not being taken into account	792 to 880
Men drawing sledges	627
A man drawing a boat on a canal 50,000 kilogrammes transported 11 kilometres	550,000

Summary of Experiments on the daily Labour of Horses : —

	Daily Labour measured by the draught and the road gone over.	Useful Effect.
Waggon horse	5600	
Poste horse	3420	
Mill horse		585
Ditto	1684	842
Ditto	1185	595
Ditto	2948	675
Ditto		1560
Barge horse	800	

We see by the first summary that a man who mounts a ladder freely without any load can furnish a quantity of action double that which he affords with crochets, cords, pulleys, or winches.

In considering the useful effect of a wood porter in houses, it is expressed by the number 56, which is only the quarter of 225, the measure of the first daily action: it results that if a man mounts a staircase freely, and lets himself fall by means attached to the extremity of the cord of a pulley, he would elevate a weight equal to his own at the other extremity of the cord; he would produce nearly the same useful effect as four men lifting the same weight on their backs or with crochets.

It will be conceived that a man could elevate a load by a ladder greater in proportion as the weight is equally distributed over all the active parts of his body, but the weight of the man himself fulfils this condition to its greatest possible extent. This theory confirms the result of experiment on the best employment of the greatest daily labour a man is capable of.

Applying the same reasoning to a horse, it is easy to calculate the useful effect produced by his mounting a slope. Let us suppose that he elevates himself in a day to 20 kilometres, his weight being about 250 kilogrammes, he would elevate the same weight to the same height by letting himself fall, and his daily labour would be expressed by 5000, a number six times greater than that which expresses the daily labour of a horse drawing a boat, and which we generally regard as the mean action answering to a number of horses. There would therefore be a great advantage in employing a horse as a weight capable of lifting, even when we reduce the height to 10 kilometres, which he might mount in a day.

The Measure of the greatest Effort of an animated Mover. — We have seen that the daily labour of animated mover depends on three elements: the pressure which he exercises on the resistance to be overcome; the velocity of the centre of application of the pressure; and lastly, the duration of the pressure. There is such a relation between the two elements pressure and velocity, that if one attain its maximum the other becomes nothing. The greatest velocities observed among men and horses are respectively 8 and 15 metres per second; a man running with this velocity consumes in half a minute the labour he is capable of in a day. The horse consumes the same in 7 or 8 minutes, and if he be

harnessed to a car, a course of 2′ 13″ suffices to exhaust his daily labour. The dynamometer shows the pressure which a mover exercises on a fixed obstacle, and experiments on individuals more or less strongly constituted prove that the greatest pressure which a man exercises on a spring with his hands varies from 50 to 71 kilogrammes. The scale of traction on the same dynamometer gives 140 to 150 kilogrammes as the greatest weight which a man can lift with the aid of his hands and loins. It is generally believed that the muscular strength of man in his savage state surpasses that of the workmen of civilised countries. Experiments made on the New Hollanders by M. Peron, the naturalist, prove that the English and French sailors have nearly the same strength as these savages in pressing with their hands, and are far superior to them in the action of the loins: the mean measure of this action being 100 kilogrammes for the former, and 128 for the latter.

To measure the greatest effort of a horse harnessed to a vehicle, we attach the dynamometer by one of its extremities, and the other to a large spring of wood which stretches it gradually; or, if we have a row of continuous sledges heavily laden and fastened together by pieces of chain of a certain length, the horse then draws the first sledges, and successively those which are behind, until the resistance, increasing with the number of sledges put in motion, equalises the greatest effort of the horse: by this procedure time is allowed the horse to arrive at his maximum of effort. This maximum varies, according to the scale of traction on the dynamometer, from 300 to 525 kilogrammes.

Whatever is the moving power there is always a certain relation between the quantities which express the pressure and velocity at each instant of daily labour, and these two elements have their maximum. We find in the volumes of the Academie of Petersburg, 1750–1751, 1760–1761, two memoirs of Euler on this question. This geometrician has in his second memoir considered an animated mover as a source of water falling from a determined height, and the resistance as the effort capable of turning a water-wheel whose float-boards receive the shock of the water. We call h the fall of water, a^2 the surface of the float-board struck by the water, a^2h is the expression of the maximum of the pressure of the water on the float-board: calling A the maximum effort of the mover Euler supposes $A = a^2h$, calling v the velocity of the water at the end of its fall, and before the shock on the float-board he makes it equal to the velocity of the mover walking freely without a load.

He designates by the letter u the velocity of the float-board after the shock of the water, and makes it equal to the velocity of the mover which corresponds to the daily action: he calls A′ the pressure of the water on the float-board, which is equal to the pressure of the mover corresponding to the velocity a: lastly, Euler admits, considering only the action of the water on the float-board, that we have the equation $A' = A\left(1-\frac{u}{5}\right)^2$.

To verify this formula as applied to animated movers, man for example, Schulze made some experiments which are described in a memoir to the Academy of Berlin, 1783. He selected seven men, differing from each other in weight and shape, he found that when he made them draw horizontally from below the shoulder, a cord passing over a pulley to the extremity of which weights were suspended, the men experimented upon stopped successively at the 7 following weights:

95 105 110 100 105 100 115 livres.

The sum of these weights, 730 livres, is the measure of the maximum effort of the seven men acting in concert: the velocity of these same men walking freely without a load was found to be $5\frac{3}{10}$ Rhine feet per second. To find the velocity corresponding to their daily action Schulze used a machine whose levers were fixed in a vertical axle, to which two great cylinders of marble turning with the axle were attached: a horse was usually harnessed to this machine whose radius was 10 Rhenish feet.

Substituting for the daily labour of a horse that of 7 men working together, he observed that the velocity of these men in the machine was 2·45 Rhenish feet per second: of the four quantities A′, A, v, u, three are known, for we have

$$A = 730 \text{ livres}; \quad v = 5\tfrac{3}{10} \text{ feet}; \quad u = 2{\cdot}45 \text{ feet}.$$

Substituting these numbers for the preceding formula, it gives $A' = 205$ livres for the pressure corresponding to the daily action.

Having fixed the extremity of the cord on the vertical axis, and having rolled it round the axis, he passed it over a pulley whence it hung over the well; he then attached divers weights to the other extremity of the cord: a weight of 215 livres gave a uniform velocity of 2·4 feet Rhenish per second, nearly equal to that of the men applied to the machine: thus the pressure A′, as found by the formula of Euler, was equivalent to a weight of 205 livres, differing 10 livres or $\frac{1}{20}$ from the observed pressure, 215 livres.

In this experiment the mean value of the draught of a horse in the machine is 205 livres, or about 100 kilogrammes: if we apply the formula of Euler to a horse harnessed to the machine, taking the facts as given before, we have for the greatest mean effort of the horse

400 kilogrammes; his velocity at the ordinary pace without a load is 1·6 metres, his velocity in the machine is 0·8 metres; we have then

$$A = 400 \text{ kilogrammes}; \quad v = 1{\cdot}6 \text{ metres}; \quad u = 0{\cdot}8 \text{ metre}.$$

The formula gives $A' = 400\left(1-\frac{1}{2}\right)^2$, or 100 kilogrammes, which is confirmed by experiment.

We must remark that the formula of Euler, which determines with sufficient precision the pressure corresponding to the daily labour of animated movers as compared to water, is not by any means satisfactory for the calculation of the effects of this fluid on the water-wheel. When treating of this fluid as a moving power we shall give another formula, which affords results approaching near to those observed.

CHAP. XVI.

HYDROSTATICS.

Hydrostatics which teaches of the equilibrium of fluids, and that a fluid is composed of material particles, infinitely small, and move without friction on each other in every direction; this property it is which occasions it to communicate pressure equally in all directions: for the purpose of examining these qualities, it is necessary that we should leave out of our consideration, all which relates either to their expansibility or compressibility, their cohesion and capillary attraction. We must also view them as having a uniform density throughout.

One of the first laws which is apparent is that the surface of such a fluid, when at rest, assumes the horizontal: the face, however, always being perpendicular to the direction of all the forces which act upon it, the power of gravitation having the effect upon the waters of the ocean, of occasioning it to lie in parallel lines with the earth's curvature. We find also that when any part of a fluid is raised above the surface, it will quickly return to its level, from whence we learn that the pressure of a fluid on every particle of the vessel containing it, or any other surface in contact with it, is equal to the weight of a column of the fluid of which the base is equal to that particle, and the height to its depth below the surface of the fluid: so that in a cistern 10 feet deep, each square foot will sustain the weight of 10 cube feet of the liquid, or 10,000 ounces; in a vessel filled with mercury, an inch in depth, each square foot will sustain a pressure of 1130 ounces; the atmosphere has a pressure upon each square foot of the earth's surface of 34,000 ounces, which is equivalent to the weight of a column of mercury 30 inches high. It is therefore obvious that the pressure on every square foot of the bank of a river increases continually in descending towards the bottom.

Of the Level of Liquids and their Equilibrium. — Liquids, like other heavy bodies, tend always towards the earth's centre, and descend as low as possible unless some obstacle prevents them. Water poured into a vessel and left to itself always assumes its level, for if there is at first one part of its surface more elevated than another, it will descend towards the lower as on an inclined plane, or as along several contiguous inclined planes, if it make a species of curve. If there be still some places higher than others, the same will happen to each of them; the most elevated parts, if they can, will descend as low as possible, and when there is no longer any agitation on the surface, it will be found level, since all its points are equidistant from the earth's centre, and will always maintain themselves in this state, if they are not put in motion.

When the surface of a liquid is level, all the columns of which this liquid is composed are in equilibrio. — Suppose we pour water into the prismatic vessel B C, and that we suppose this water divided into columns of equal bases, that the surface A E of the first column B E should be level with the surface E F of the second; it is necessary that these two columns should counterbalance each other, and tend mutually to raise each other by an equal effort on their bases, otherwise if the first bore upon the second, the surface of this second, rising above that of the first, could not maintain itself in this position, because, not being sustained at the sides, it would fall on the first in order to assume its level. In like manner the second column, E M, could not by its own weight bear upon the third, M G, without the surface of the latter mounting, and the former descending, but these two columns being of an equal weight, there is no reason why one should bear upon the other; in like manner all those which follow sustain each other reciprocally in equilibrio.

Hence when we mix two liquids together, one of which is lighter than the other, as oil and water, the heaviest compels the lightest to rise to the surface; nevertheless it appears that it is the oil which separates itself from the water.

Although the columns E M, M G, G O, O I, I Q, Q D, appear to unite themselves against B E to surmount it, this latter is not in equilibrio with all the others, together or separately, because they are divided among themselves, each tending to raise the other; that is to say, the columns E M, M G, G O, O I, I Q, in like manner unite with the first B E, against the single one Q D, because if each of these columns be opposed by all the others, it is also supported by the others, and acts against each in particular: whence it follows that the column E L, C D, composed of several small ones, has no more advantage over the single one B E than this has over the preceding, which proves that a column of liquid, however large it may be, balances the last thread of the same liquid when both are level, because the larger column is composed of threads similar to the first, which oppose each other, and unite with the first against each other as they all united against the first: all the columns of the same liquid are then in equilibrio, their surfaces are level, and as their surfaces are level, these columns are in equilibrio.

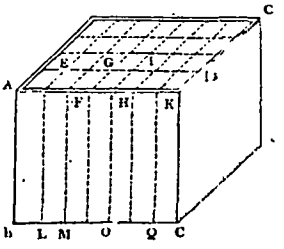


Fig. 1658.

If the vessel be of any other form than prismatic, it is only necessary to conceive it divided by horizontal sections from the bottom X to the edge A C, in such a manner that each section may be regarded as a small prism; pouring the liquid gently along the edge of the vessel, it will level itself in the prism R X T; then in the second, N P, having the first for its base; then in the third, I O, which has the second for its base, and so on to the last, A C.

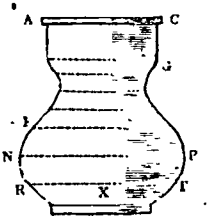


Fig. 1659.

If we have a siphon, whose branches A B, C D, E F, G H, we suppose vertical, and of the same size, it cannot be doubted that the liquid poured into the first branch, A C, to a certain height, L M, will mount in another branch, E G, to a height N O, equal to the preceding; for on account of the pipe of communication C I K F, the column L C will raise the column N G until it is in equilibrio with it. These two columns being equal in size, they must also be of the same height, to weigh equally the two tubes A C and E G being to be regarded as the scales of a balance which contain equal weights, and the pipe of communication as the beam round which the two columns of water are in equilibrio, and consequently their surfaces level. With regard to the pipe of communication, it is evident that its length does not affect the equilibrium of the two columns: we may regard it as not existing, that is to say, as if the two branches of the siphon were contiguous, separated only by a diaphragm, for as long as the communication is horizontal, the water contained cannot increase in one branch to the prejudice of the other.

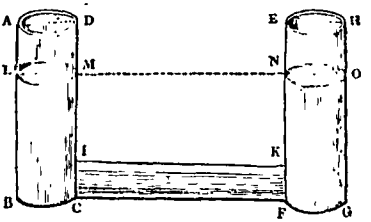


Fig. 1660.

If the first column A B C D were less than the second E F P Q, the columns of the same liquid, K C and M P, would not the less be in equilibrio; for if we cut off from the second column another, M G, of the same size as the first, it is evident that the latter will

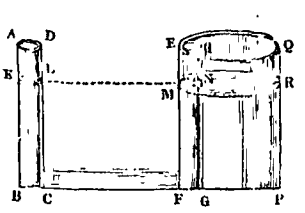


Fig. 1661.

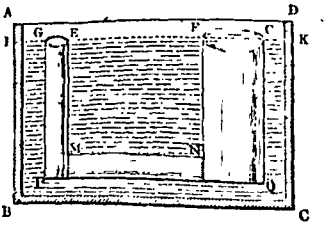


Fig. 1662.

only have to oppose M G, which has the same base as itself: since the column M G will be in equilibrio with the rest of the liquid of the branch E P, and also with the column K C, the latter will be in equilibrio with the whole column M P.

Having a vessel, A B C D, filled with any fluid to the level I K, let us imagine that in this vessel we form with the same liquid a glass siphon G E M N F H Q P G, serving as a diaphragm, it is evident that this liquid, which the siphon would contain, should be in the same state as it was before its separation from what remains in the vessel; but as, before the formation of the siphon, the parts of the liquid which it contains were in equilibrio, and the surfaces G E and F H level, the same things would still subsist.

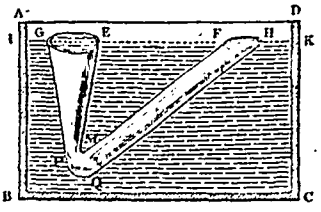


Fig. 1663.

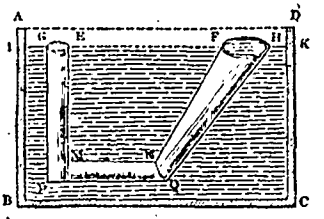


Fig. 1664.

The liquid contained in the siphon having nothing in common with what remains in the vessel, if we suppose the latter annihilated, and the glass siphon transformed into some other material, as copper or tin, we shall see that water poured into a siphon of any figure will assume its level in the two branches, and maintain its equilibrium, however unequal the size of these branches may be: notwithstanding this law of nature, there are cases in which liquids do not rise to their level, as will be noticed hereafter.

If we have a tube open at both ends, and we plunge a part perpendicularly into the water, it enters therein and maintains the level of the surface of the water, since we may regard it as a column which is in equilibrio with that without, in the same manner as it was previous to its inclosure in the tube; but what is surprising, this does not happen in all tubes; and in capillary tubes, or those of very small diameter, the water mounts above the level of that which is outside, and the higher in proportion as the diameter is less.

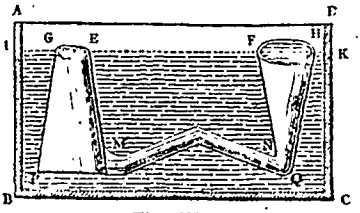


Fig. 1665.

All columns of water tend by their weight to descend and raise each other, and it is the equality of their force which keeps them level: if it should happen that one of these columns were lighter than the others it would immediately rise above the others to the height necessary for the equilibrium. When a capillary tube is placed on the surface of the water, the drops of which are comprised in its opening attach themselves to the interior of the small circle which forms it, are sustained by it in part, and consequently are so much the lighter with regard to the water, which acts freely on the bottom of the vessel. Then the column of water, which answers to the opening of the capillary tube, exercises its weight less on the bottom of the vessel than the other columns, with which it is surrounded, so these latter ought to elevate it in the capillary tube to a height at which it regains by a greater quantity of water the weight by which it is deficient with regard to the bottom of the vessel, to be in part sustained by the drops of water which adhere to the tube. It follows that the smaller the diameter of the tube is, the more the water within would elevate itself above the level of the other, as having more surface in proportion as a greater number of drops of water are sustained by it; and those of the middle will have so many the more leaning points in the part of the preceding, as the tube is narrow.

Another experiment which appears contrary to liquids always keeping in equilibrio. — Having a vessel A B in which water or any other liquid is placed to any height C D, if we take a piece of cloth and dip it in the water, then placing it on the edge of the vessel so that the part G H dips in the water, and the other E F is outside the vessel, and sufficiently long for its extremity E to be below the surface C D of the liquid, we shall see it mount along the band, drop from the extremity E, and the vessel will be entirely emptied if the extremity H reaches the bottom.

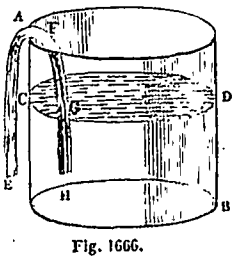


Fig. 1666.

Gardeners adopt this method to water plants which require to be kept moist, and chemists apply it in a way which from its singularity requires mentioning. When they have several liquids mixed which they desire to separate, they dip cloth bands into each of the pure liquids; they then dispose these bands on the edge of the vessel, and each distils the liquid with which it was wetted, as well in a vacuum as in a plenum.

To compare the specific weights of different liquids an instrument invented by Homberg is used, called an areometer, composed of a small phial E, having two necks A B, D C, very narrow, but the second still narrower than the first: through the opening A with a funnel F, the liquid to be weighed is poured, which as it falls into E drives out the air through the tube C D, and the place exactly marked at G on the neck A B, to which the liquid reaches: having weighed the phial full of liquid in a good balance, and the weight of the empty areometer subtracted, the weight of the liquid poured in is obtained; the areometer is then emptied, cleaned, and filled with another liquid to the same mark G, which is weighed as before, to obtain the ratio of the specific weights of these two liquids. As liquids are subject to dilate with heat and contract with cold, Homberg reports his experiments on their weights, and remarks on their difference in the greatest heat of summer and in the greatest cold of winter, so as to ascertain very nearly the difference between these two extremities at the times in which the areometer is used.

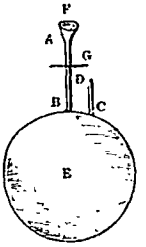


Fig. 1667.

On the vertical Action of Water against the Sides of the Vessel containing it. — One of the properties of liquids is the effort which they make in every direction against the sides of the vessel containing them, caused by the motions of their parts, which being detached from each other only seek to escape.

Having a right tube, A B C D, open at both ends fixed against a vertical surface, if we introduce into this tube at the lower end a piston G H I to serve as a bottom, and pour water to any height E F, the power applied to this piston will sustain a weight equal to that of the column of water contained in the tube. If we pay attention to the fact that liquids have this property in common, that the motion of their parts in every direction, and the effort they make sideways to discharge the pressure of those with which they are loaded, diminishes nothing of the action of the weight which causes them to tend towards the earth's centre like all other bodies, we shall find that the power P being in the direction of the line K L drawn through the centre of gravity of the column G E F H cannot prevent this column from descending without sustaining the whole weight: another proof that this power is in equilibrio with the weight of the column of water which it sustains, is, that if we push the piston from below upwards, to make it ascend, this column of water will have the same velocity, and consequently the same quantity of motion.

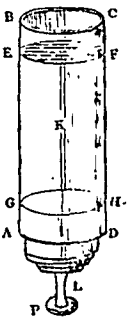


Fig. 1668.

To estimate the effort which the power makes, suppose that the diameter of the tube, or that of the piston, is *5* inches, and the height E G 18 inches; the superficies of circles being as the squares of their diameters, we can, by using the weight of the cylindrical foot of water, which was found to be *55* lbs., say, as the square of 12 is to the square of *5*, or as 144 is to 25, so is *55* to the fourth term, which we shall find is 9 pounds 8 ounces, for the weight of a cylinder of water whose base is a circle *5* inches diameter and whose height is a foot: but as the column is 1 foot 6 inches in height, its weight will be 14 pounds 5 ounces.

It will be remarked that if the circle G H of the piston were less than the bottom A D, the power P would only sustain the weight of a column of water L I K M, which has for its base the circle of the piston, and for its height the level of the water above the same piston, since it can only sustain the column of water to which it is a base, all the others, which make the difference of the columns A E F D and L I K M, resting on the bottom A D. We may add that if the power works the piston so as to elevate the column which it sustains, it would be easier than if this column were enclosed in a tube, in which we must surmount the resistance which causes the friction, or the friction of the water against its sides.

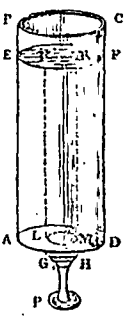


Fig. 1669.

Having a siphon consisting of two branches A B, C D of the same diameter, place in the second a piston I L K at a determined height I K; pour water into the first branch to the height E F; it cannot rise to this level in the second, on account of the obstacle which the piston presents. If we draw the horizontal line G K, the columns A H and M K, having their surfaces level, would be in equilibrio if they made an equal effort on their base to surmount each other; but as the first sustains all the weight of the column G F, A F, which is composed of the two, will push with the weight of the part G F the latter from below upwards, to make it rise to the level E Q. Thus subtracting the friction and weight of the piston, we must, to prevent it from yielding to the effort which the column M K makes to lift it, load it with a weight equal to that of the column G F, which is too natural to need any further explanation.

Although the branches of a siphon were of unequal thickness, the water in the lesser one, Q Q, as we have observed, was not the less in equilibrio with that of the larger one, M K, while their surfaces were level, because the lesser one is in equilibrio with all those of which the larger is composed. If water is poured into the small tube R O, to the height N, the column N O will make an effort to raise all those of the branch M K to the level E Q, which will push the piston I K from below upwards, with as much force as the column G F would; consequently, in order to maintain the piston at the height I K, it must be loaded with a weight equal to that of the column. As the size of the branch N O is indifferent, we find that if it were reduced to contain only a thread of water, this thread would sustain in equilibrio the weight with which the piston is loaded.

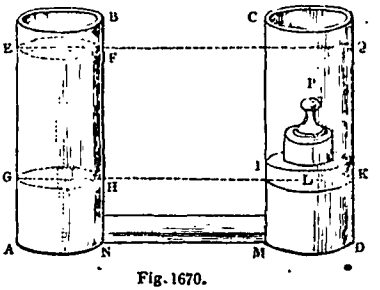


Fig. 1670.

Suppose that the superficies of the circle of the thread N Q is $\frac{1}{1000}$ of that of the diameter G H or I K, the weight of this thread $\frac{1}{1000}$ of that of the column G F, or of the weight with which the piston is loaded. If we also suppose that the piston descends the height of one line, this could not happen without 1000 small columns, each a line in height, and of a diameter equal N Q, passing into the tube Q R, and without this column mounting in the tube 1000 times as high as the piston descended; whence it follows that the weight of the fillet and that of the piston, being in the reciprocal ratio of their velocity, these two weights are in equilibrio. It follows that if the thread N Q were 10 feet in height, and the piston I K 1 foot in diameter, the weight loading the piston must be 550 pounds to be in equilibrio with this fillet, although it would only contain 1 ounce weight of water.

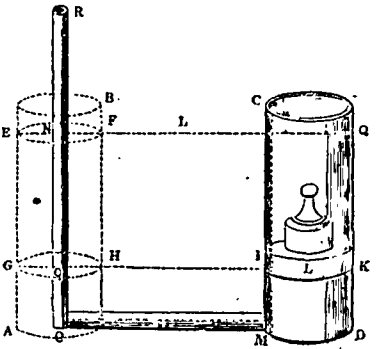


Fig. 1671.

When a mass of fluid in a state of equilibrium is subjected to the action of any forces, every particle is pressed equally in every direction, and *vice versâ*, if every particle of the fluid mass be pressed equally in every direction the whole mass will be in equilibrio: for since the parts of a fluid yield to the smallest pressure, any particle more pressed in one direction than another would move to the side where the pressure was least, and consequently the equilibrium would be destroyed; if the particles are equally pressed in every direction, it is evident that the mass of which they are composed must be in equilibrio, a principle adopted by Euler, D'Alembert, Bossut, and Prony: and the pressure exerted by a fluid upon any given portion of the vessel which contains it is equal to the column of the fluid whose base is the area of the given portion, and whose altitude is the depth of the centre of gravity of the portion below the fluid surface.

A single column of water may be in equilibrio with an infinity of others, together or separately.—If we have a tube F M larger below than above, to receive a number of small tubes A B, ending in a cylinder D E closed by a piston, if we pour water through the orifice E, to fill all these tubes and their cylinders, the single column G M being 10 feet high, and each cylinder 1 foot in diameter; this column alone would sustain as many times 550 pounds as this machine, which resembles a lustre, had branches. Although the length and thickness of the tube of communication O M only contributes indirectly to the effect which we have described in fig. 1671., we may suppress this tube, and show the same things with a machine yet simpler than the siphon.

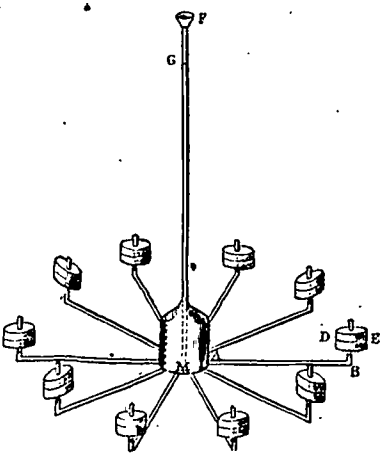


Fig. 1672.

Let A B C D be a cylinder attached to a vertical surface, having for its bottom the circle K L of a piston, and closed above with a plate of metal soldered so as not to be detached by any effort made to raise it: in the middle is a hole answering to the tube F E, which may be only one line in diameter; if we fill the cylinder and tube to the respective heights E, G, the power applied to the piston will sustain a weight equal to that of the column K H I L, having for its base the circle of the piston, and for its height that of the column G N.

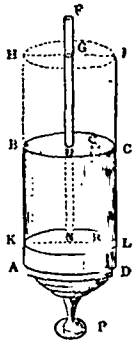


Fig. 1673.

To prove this we must remark that the column G N being higher than all the others O R contained in the cylinder K B C L, these latter, tending to rise to the level H I, will push the surface B C from below upwards with a force equal to the weight of a column of water, B H I C, minus the weight of the column G F.

If we have already remarked that a power of whatever nature it is cannot make any effort by pushing or pressing a body without a fulcrum which is always loaded with the effort which this power makes, we shall find that all the fillets, as O R, having for their fulcrum the circle of the piston, cannot push the surface B C from below upwards without pushing the bottom K L with the same force downwards, consequently the power will have to sustain the action of a force equal to the weight of a column of water, such as B H I C; and as on the other hand, it actually sustains the weight of that which is contained in the cylinder, K B C L, it will therefore sustain the action of a power equivalent to the weight of the column K H I L.

As a second proof we may add that if the circle of the column G N were $\frac{1}{1000}$ part of that of the piston, the power could not make the piston descend one line without the level G of the column G N descending 1000 times as much: and, as in the state of equilibrium, the weight of this thread and the power P should be in the reciprocal ratio of their velocities, or of the spaces gone over in equal times; it follows that the power must be equivalent to the weight of a column 1000 times greater than G N, or to that of the column K H I L.

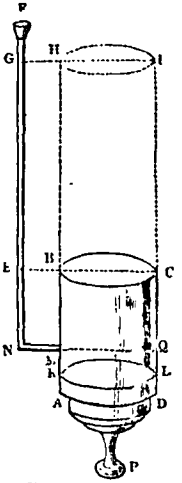


Fig. 1674.

Suppose the cylinder A B C D similar in every respect to the preceding, with this difference only, that the pipe, instead of being adapted to the upper surface B C, is fitted to the side B A, the same thing will happen. To prove this let us prolong the horizontal line N M, and take the line M Q for a diaphragm, which divides the cylinder K B C L into two parts. If we regard the pipes F N and M B C Q as the branches of a siphon of which N M is the communication; the column G N will cause all those of which the branch M B C Q is composed to push the surface B C from below upwards, with a force equal to the weight of a column of water whose base is the circle B C, and its height G E or H B. But, as we have just seen, this cannot happen without the bottom M Q being pressed from below upwards with a force equivalent to the weight of the column M H I Q; if we suppress the diaphragm M Q, the preceding pressure, having no other fulcrum than the circle K L of the piston, which is also loaded with the weight of water comprised in the part K M Q L, the piston will sustain a weight equal to that of the column of water K H I L.

From the preceding example we learn that if we have a vessel A H well closed on all sides, and that to one of the small faces E H we have adapted a curved tube K N F, and if we pour water through the orifice F to fill the vessel and tube, to the height G, the single column G N will cause the bottom A R Q E to be pressed by a weight equivalent to that of the water which can be contained in the parallelepiped A M P Q, which has this bottom for its base, and the level G of the water in the tube above the same bottom for its height, and that the upper surface is pressed from below upwards by a force equal to the weight of water which the parallelepiped C M O D can contain.

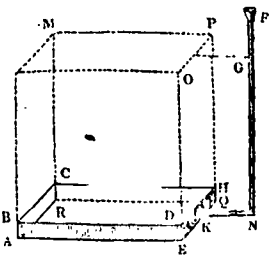


Fig. 1675.

As the distance D E of the two opposite surfaces R E and B H is indifferent to the action of the water which presses the second from below upwards, we see that they may approach each other as near as possible, provided they do not touch; the water of the tube will always have this effect, consequently in this case, as in the preceding, it is not the quantity of water used which increases the

effect, which only depends on its elevation in the tube, and the extent of the base over which it is spread.

Supposing the surfaces C D and A Q, each 6 feet square, are so near each other that we can still take something from the interval; if we give 24 feet to the height of the column G N, each surface will be driven in the opposite direction by a force of 60480 pounds, and produced by a weight of 3 or 4 ounces.

Belidor took two plates, each 1 foot square and 30 lines thick: having placed them above each other, about 3 inches apart, he nailed a leather band all round, and formed a kind of bellows, having the form of a parallelepiped. After having taken all proper precautions to prevent the water with which it was filled from escaping, he attached the upper surfaces in a firm manner horizontally to a beam supported by two uprights, so as to make the bottom work upwards; at the four corners of this were iron rings answering to cords attached to the arm of a balance; he then loaded the other arm as much as possible, so that the lower part of the machine was applied to the upper: this latter was pierced with two holes, to one of which a vertical plug was adapted to be opened, solely for the escape of the air when water was poured in: at the other was a copper tube, whose interior diameter was 3 lines and 10 feet high, attached to a beam firmly fixed at both ends.

The question he wished to solve was, if by pouring water into the tube it would raise a weight of a column of water 1 foot square at the base and 10 feet high; this happened when about 3 pints of water were poured into it; he then remarked that the velocity of the weight increased as it elevated, for, as by pouring the water in, he took care to keep a funnel soldered to the summit of the tube full, the water with which the bellows was filled would increase by its own weight the action of that of the tube.

As the gates of a canal often sustain 22 and 23 feet of water when the sea is low, it happens that small threads pass under the sill, and insinuate themselves below the platform and foundations; this water not finding means of escaping, pushes upwards everything which could prevent it from mounting to the level of the canal, and causes the gates to bend, notwithstanding their weight and solidity.

Having a cylindrical tube, A B C D, inclined on its base A D, supposed horizontal, and filled with water to a height E F, it would load the bottom A D as much as if it were an upright cylinder A G H D of the same base. Draw through any point P of the height F I the horizontal line L M, and consider that the water enclosed in the space A E G is sustained by the side E A; then all the threads K, L of which it is composed have each a lean on the point L of the inclined surface E A; consequently the base A D is not charged therewith.

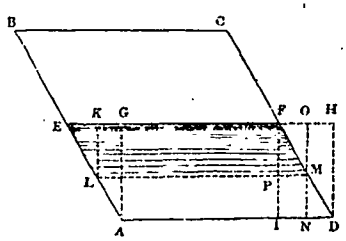


Fig. 1676.

It is not the same with that which comprises the opposite space I F D, for as the thread F I acts on the smaller M N, to elevate them to the height of the level E H, being prevented by the surface F D, each of them will press all the points M of this surface from below upwards, with a force equivalent to the weight of the thread F P, the difference of F I from M N; and as the height F P is equal to K L, the point M will be as much pressed from below upwards as the point L is from above downwards, which shows that the surfaces E A and F D are driven in opposite directions with a force equivalent to the weight of water enclosed in the space A E G, or what is equal to it, D F H. But as all the threads whose action is sustained by the surface F D cannot press it from below upwards without pressing as much the point I D of the bottom, which serves as a base, from above downwards, we see that if we add to this latter pressure the weight of the threads which the space I F D contains, each point of the bottom A D will be loaded with a weight equivalent to that of the thread F I.

It follows that having a vessel B C D E similar to a reversed truncated cone, to which the tube A B E F is fitted to receive a piston serving as a bottom; filling this vessel with water, the power applied to the piston will only sustain the weight of the column B G H E; then all the remainder of the water will rest on the sides C B and D E. This consequence shows the error of making the pipes of descent larger above than below, with the intention of giving more elevation to a fountain in which the pipe terminates, forgetting that the portion leaning on the sides of the tube does not contribute to drive that which descends; this practice, however, may be useful when the hole through which the jet issues is too large.

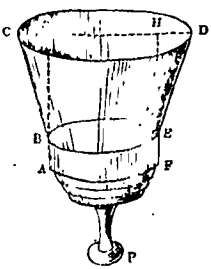


Fig. 1677.

If a piston answered to the great circle of the preceding vessel, it would happen, on the contrary, that being filled with

water, the power would sustain a weight equal to that of the column A I K C: if we close the orifice E H, and hold a tube F B filled with water to the height G, all the points of the base A C being pressed with the same force as the fillet G N presses the point N, the power would sustain a weight equal to that of the water which the column A L M C would comprise, provided, as already observed, that this vessel is attached to a fixed plan.

As a power cannot act in any direction without a fulcrum, it is necessary, in order that the piston may press upwards with the same force that the water presses downwards, that the machine should be fixed, otherwise the action of the water would raise the vessel, and leave the piston unmoved by the power: if the water were to freeze, then, being without action, the fulcrum would become useless, and the machine would only be charged with the real weight of the water and the machine.

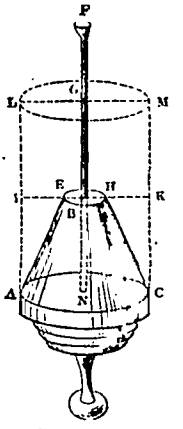


Fig. 1678.

Fig. 1679. Suppose we take another pipe A B C D, where none of the points of the level E F of the water answer to the bottom A D, and we suppose that the column A E F D is divided into several others, G F, I H, A K, by planes G H, I K, parallel to the horizon: the base G H will be loaded with a weight equal to that of the column G L M H, in fig. 1676. If we suppress the diaphragm G H the column N O, having no other base than the summit N of the column N I, these two together will only make one, O I, which communicates with all those enclosed in the space I T K; these latter will each press the base I K with as much force as the first O I: thus this base will be loaded with a weight equal to that of the water which the column I O P K comprises. In the same manner, since the point Q of the base I K is pressed with a force equal to the weight of the columns O I or R Q, suppressing the diaphragm I K, the columns R Q and Q A only composing one, R A, which is in equilibrio with all those comprised by the space A V D, the bottom, A D, will be loaded with the water of the oblique column A E F D, which would be the case if the column were straight, A R S D.

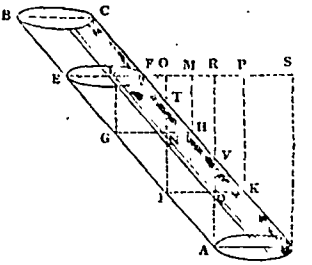


Fig. 1679.

Fig. 1680. If we have a tube whose parts, B D, D F, F Q, were disposed in zigzag, and this tube, which we suppose placed against one or more vertical surfaces, were filled with water, the bottom B E would be loaded with a weight equal to that of a column of water B K O E, having the same base, and the line B K, which expresses the elevation of the level H Q of the water above the base B E, for its height. Regarding the line F G as the bottom of the tube F Q, the water of this tube will load the bottom as much as that contained in the column F L I Q; suppressing the diaphragm F G, the column L G, having no other base than the film F G, will increase with its whole weight that of the column F D, and the bottom C D will be loaded with a weight equal to that of the column C M N D: we shall also find that the base B E, being loaded with a weight of the right and inclined columns M D and D B, will be in the same case as if it served as the base of the column B K O E. If the tube, instead of being zigzag, were serpentine, the same principle would hold good, for, by dividing the water of the tube in horizontal sections, we divide it into small right or inclined cylinders, which being contiguous may be regarded as the tracts of a tube like the preceding: whatever be the size of a tube, whether it be uniform or not through its whole extent, in whatever manner its parts are disposed, whether in a vertical or inclined plane, the power applied to a piston of an equal, greater, or less diameter than the bottom of the tube, it will always be loaded with the weight of a column having for its base the circle of the piston, and for its height that of the level of the water above the same piston.

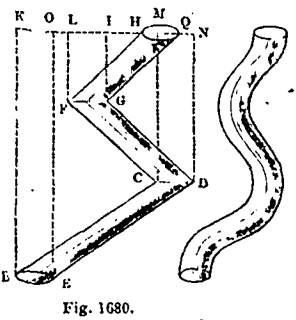


Fig. 1680.

On the Action of Water against vertical and rectangular Surfaces. — After having shown the manner in which water acts to surmount the resistance of surfaces which prevent it from descending towards the earth's centre, or from rising to its level, we shall proceed to explain according to what law it presses the sides of the vessels containing it apart; but first it must be observed that this pressure is always made in a horizontal direction: sup-

pose a cylinder of water suspended in the air without being enclosed in a tube, composed of a great number of circles of an equal thickness, the highest circle pushing the second, so that it should always preserve the circular figure and the same thickness, which could not happen without all the portions of water being driven forwards in the direction of the radii to occupy a larger circle. If this latter, so increased, were to mix in like manner with the third, the parcels of water would be still farther pressed in the direction of the radii, to occupy a larger circle than the second: in like manner, the course of all the circles of which the cylinder is composed would be extended, and the circumference of the latter would be as much increased as the number of circles was greater, or as the cylinder was higher.

If the cylinder be enclosed in a tube, all the circles of water, having the same tendency to mix, will make an effort to spread out; but as this effort can only be exercised against the sides of the tube, we see that they will be pressed from the centre to the circumference, consequently, in horizontal directions, with a force which will always increase from the top to the bottom of the tube.

Fig. 1681. Instead of a cylinder, if we take a prism A E, the water of which is divided into an infinity of films of an imperceptible thickness, the upper will always make an effort to mix with those below; these latter tending to extend will drive the surface of the prism in a horizontal direction: as we suppose that these films have an equal weight, the second being loaded with the first, will drive the rectangle 2, which sustains it, with a force twice that which will press rectangle 1, whatever be its dimensions: in like manner, the third film, being loaded with the weight of the first and second, will press the rectangle 3 with a force triple that of the first, and so of the others, whose pressure will be proportioned to the weight with which they are loaded. Now, as this weight increases in the order of the terms of an arithmetical progression, the pressures also, increasing in the same order, may be expressed by the elements of a triangle A L D whose height is that of the water: thus we find that the pressures which answer to the elements N O and P Q of the surface A B C D, are in the ratio of the elements F G and H I of the triangle A L D, or of the height L R and S L of the water above the same elements; then F G : G I : : L R : L S. It follows that the sum of all the pressures of the height L R, or the pressure which sustains the surface N B C O, will be to the sum of all the pressures of the height L M, or to the pressure which the surface A B C D sustains, as the superficies of the triangle F L G is to that of the triangle A L D, or as the square of the perpendicular L R is to that of the perpendicular L M; and when the surfaces have the same base, their pressures, beginning from the level of the water, are in the proportion of the squares of the heights of the water which sustain them. The pressure which answers to the height R S, and which the surface P N O Q sustains, being to be expressed by the trapezium H F G I, the difference of the triangles H L I and F L G, we see that it may also be expressed by the difference of the squares of the heights of the water, L S and L R.

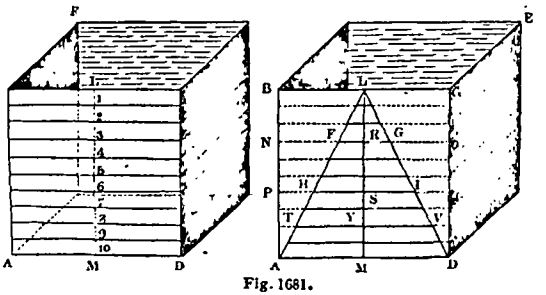


Fig. 1681.

Fig. 1682. The line B C expressing the level of the water, if we prolong it from C to R, to serve as the axis to a demi-parabola C L O, described at pleasure, drawing any number of parallels to the line B R, as F H, I L, A M, the pressures which the surfaces B G, B K, B D, sustain will be to each other in the ratio of the ordinates G H, K L, D M, drawn from the tangent to the parabola, which is very evident, since these ordinates are in the ratio of the squares of the sections C G, G K, C D, which mark the height of the water which these surfaces sustain; consequently, if from the points H and L we draw the parallels H P and L Q to the tangent, the lines G H, P L, G M, which express the difference of the ordinates, will be to each other in the ratio of the pressures which the corresponding surfaces B G, F K, I D, sustain; and the pressure which the surface B D sustains, is to that which the part I D sustains, as D M is to Q M, and so of the rest.

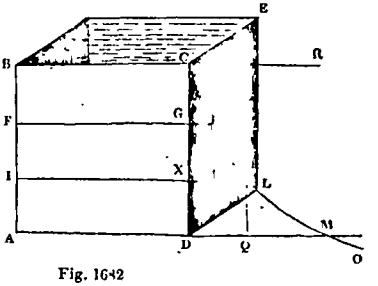


Fig. 1682

The pressures of the films which the height L M comprises being in arithmetical progression, there will be a mean pressure between the greatest and the least, which being multiplied by the weight which expresses the number of films will give a product equal to the total pressure: now, as this mean is equal to half the greatest, we shall have $\frac{A D}{2} \times L M$ for this pressure, which being equal to $\frac{L M}{2} \times A D$, we may suppose that all the films act with equal pressure, and that this force is expressed by the mean height L Z, half L M.

The pressure which the rectangle A P Q D sustains being expressed by the trapezium A H I L D, the mean element between H L and A D will express the mean pressure; and as this element can only be the line T V, which passes through the middle of the height S M of this trapezium, we may further express by the height L Y the arithmetical mean between L S and L M, supposing the pressure of each film which the surface A P Q D sustains uniform. Supposing that the films which belong to the same surface act uniformly, it follows that the pressures which two different surfaces sustain when rectangular will be in the compound ratio of the extent of the same surfaces and the mean heights answering thereto: thus, when the surfaces are equal, the pressures will be as the mean heights, and when the mean heights are equal, the pressures will be in the ratio of the surfaces.

To show the method of calculating the pressure of water against vertical surfaces we use a siphon, fig. 1683., composed of two right prismatic equal branches united by a horizontal communication pipe, I A D L M, of the same figure and size as each of the branches, separated into two parts by a diaphragm N O P Q, parallel and equal to the plane R S D T. If we pour water into the first branch, to fill only the part of the communication I A D P N, it will not make any effort to mount above the level A P, and its action will be reduced to press the sides which sustain it, among the rest the diaphragm N O P Q, in order to spread itself on the other side: but if we fill the same branch to the height V X, the column A V X D

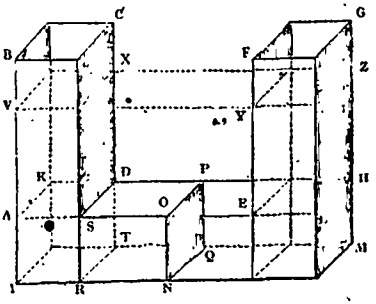


Fig. 1683.

will press the water of communication, which will be pressed from I to N in a horizontal direction, and will tend to pass into the other branch, to rise to the level Y Z, where it would elevate itself, in fact, if it were always maintained at the same height V X, and were not prevented by the surface N O P Q, which would sustain not only the pressure of the water contained in the communication, but also all that which the column A V X D may occasion, which is very evident. In fact, since no other force than the weight of this column acts here to raise the water in the other branch, and to maintain it there at the height Y Z above the level A H, it is necessary that the superficies N O P Q should be pressed in a horizontal direction by every effort of the power which prevents it from acting. Since the length of the end of the tube R D O Q is indifferent to the effort which the water makes to rise in the second branch, we may shorten it as much as we please, and even place the surface N O P Q close to its equal R S D T, which we may take for another diaphragm, in order to detach the prism I B C T from the siphon: as this does not at all change the action of the water contained in it, the surface R S D T will be pressed with as much force as the diaphragm N O P Q.

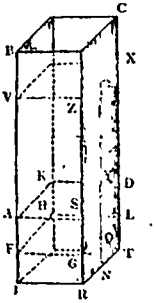


Fig. 1684.

Fig. 1684. The pressure which the surface R S D T sustains from the water enclosed in the space I A D T, independently of that caused by the column A V X D, being to be expressed by the product of this surface and the mean height P Q, and the weight of this column by the product of the base A D and the height O P, it follows that these two products taken together equal that of the surface R D by the height O Q, composed of the preceding O P and P Q; it will only express that of the pressure which the surface R D sustains: as the latter product is neither more nor less than the solidity of the prism F V X L, we see that if the pressure caused by the column A V X D against the surface R D should be expressed by its weight, all that which the same surface sustains will be, by that of the column F V X L, which has for its base the plane F H L G, equal to this surface, and for its height the line O Q, the arithmetical mean between O P and P N; which shows that if the surface R D was 4 feet, and the height O Q 10, this surface would be pressed by a force equivalent to the weight of 2800 livres, $=4 \times 10 \times 70$ livres.

If of the two branches of a siphon we leave the first as it is, and bring the opposite surfaces I H X L and B G Z M near together, to render the prism I H Z A much narrower than the other; this will not prevent water poured into one part of this new siphon from rising in the other to the same level Y Y, or from that in the second branch being in equilibrio with that in the first, because the small column I E Y A will never have to oppose any other column than one of the same base as itself, and as all the others contained in the great branch are in equilibrio with the first. As these columns make equal efforts on their bases to surmount each other, the water of communication will be pressed from & to B by the large column with the same force as from B to & by the small one; thus the diaphragm N O P Q will be pressed with equal forces in opposite directions.

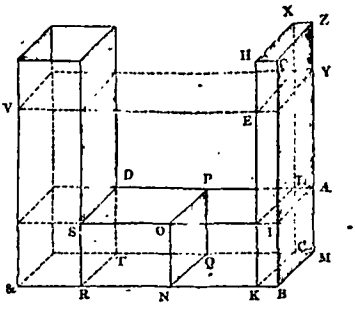


Fig. 1685.

If we suppose two other diaphragms, R S D T and K I L C, and suppress the pipe of communication, to detach the two branches, the surface R S D T will be pressed with the same force as the surface K I L C equal to the preceding, will be from B to K, both being in the same case as the diaphragm N O P Q was previously, although the surface was indifferent to the pressure it sustained. Although there is much less water in the second prism than in the first, the surface K I L C will sustain, like the other, a pressure equal to the weight of the column having this surface for its base, and the arithmetical mean between E I and E K for its height. The pressure of the water being in the compound ratio of the surfaces which sustain them and the mean heights corresponding thereto, we find that, without taking into account the dimension I R, by reason of the quantity of water which the vessel I B C T contains, there will be the same ratio between the product of the surface R S D T multiplied by the mean height C Q, and the product of the surface R Z X T, multiplied by the mean height O Y, as between the pressure which the first surface sustains and that which the second sustains. Now, since the pressure which the first sustain is equivalent to the weight of cube feet of water which the relative product gives, the pressure which the second sustains will then be equivalent to the weight of the number of cube feet of water which its relative product gives: — thus, supposing the base R T of this surface to be 2 feet, and the height O N 12 feet, it will be 24 square feet, which being multiplied by the mean height O Y, 6 feet, and the product by 70 pounds, gives 10080 pounds for the weight equivalent to the pressure which it will sustain. If the vessel, instead of being prismatic, be a tube or right cylinder, we must, to have the pressure which the surface will sustain, multiply this surface by half the height of the water.

The difficulty of raising a flood-gate arises from several causes; suppose it 5 feet wide, sustaining 8 feet height of water, the surface pressed will be 40 square feet, which being multiplied by 4 feet, the mean height, we have 160 cube feet, or 11200 pounds, for the pressure of the water, or the pressure of the vane against the grooves, of which we must take $\frac{1}{3}$ for friction, which will be about 3733 pounds, which being added to the weight of the vane, we have the resistance which the power must surmount at the first moment of its action. In the following moments this resistance will continue to lessen, because the pressure or friction diminishes in the ratio of the squares of the heights of the water which the vane sustains. It must be remarked that the vane in mounting arrives at a point of elevation at which its weight is in equilibrio with the friction, and that it is only when raised above this point that it can acquire in descending a sufficient quantity of motion or power to arrive at the sill of the gate: for as the friction will increase in the ratio of the squares of the heights of the water, while this force only increases in the ratio of the square roots of the same heights, if the gate does not fall from a point sufficiently high, it will remain suspended in its road without being able to descend except by other assistance.

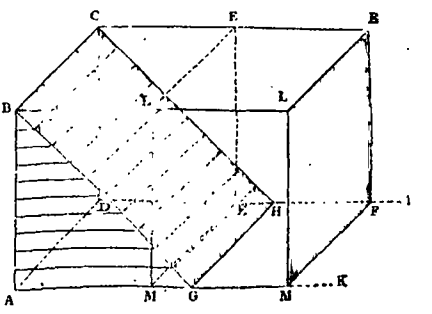


Fig. 1686.

Fig. 1686. To render still more evident the action of water against a vertical surface A B C D, we shall use the regular parallelepiped A B C D E F L M, one of whose dimensions A M will be either greater or less than the height B A of the water. We will suppose that we have taken on the lines D I and A K the parts D H and A G, each equal to

the height B A of the water, and that we draw the lines C H, B G, to form the solid A B C D H G, which will express a volume of water whose weight will be equivalent to the pressure which the surface A B C D sustains; which is very evident, since to have the value of the solid we must multiply the same surface by the half of A G, or A B. If we suppose the height B A divided into a great number of equal parts, and that through each point of the division a plane parallel to the base A H passes, the solid A B C D H G will be divided into a number of slices or prisms, and the surface A B C D into the same number of rectangles equal to each other: then the weight of the water of each slice will express the pressure which the small rectangle answering to it in surface will sustain, and these slices or prisms having the same height B C, their weight, or the pressures which they measure, will be in the ratio of the trapeziums serving as bases to these prisms.

Since we can bring the surfaces K H X C and B G Z M as near each other as we please, provided only that they do not touch, we see that with a very small quantity of water the plane K I L C will be pressed with as much force as if their distance was very great: consequently if we have a prismatic vessel, two of whose parallel and opposite faces are each 6 feet square, placed at the distance only of one line from each other; filling this vessel with water, the two surfaces will together sustain an effort of 15120 pounds. But what appears still more extraordinary is, that if we close this vessel to adapt a tube G F to it of any height, filling it with water, the surfaces will be pressed with the same force as if the vessel were filled with water to the height H I; which is very evident, for each of the columns contained in the vessel A E, and which would have for its base that of the tube F G, being pressed downwards with the same force as that of the tube presses the column F K, will make the same efforts against the sides of the vessel, as the same column F K would make against those sustaining it. Thus, supposing G F 10 feet; the mean height C L will make 13, which being multiplied by 36 feet square, and the product by 70, will make 65520 pounds for the effort which the water will make against the two surfaces together, although its weight altogether will be near 18 pounds.

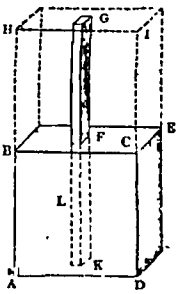


Fig. 1687.

We may observe that the pressure of the water against a vertical surface does not depend on the quantity which the vessel contains, but only on the extent of this surface and the mean height of the water.

On the Action of Water against inclined Surfaces. — Having considered the action of water against vertical surfaces, we must now examine what is the pressure those which are inclined sustain.

Suppose that the trapezium A B C D represents the profile of a vessel larger above than below, composed of plane surfaces, and filled with water to the level B C, and that it is required to measure the pressure which the inclined surface C D will sustain, not considering the breadth. From the point M draw a perpendicular, D F, to the horizontal line B C; take the part F E equal to this perpendicular and draw the line E D to have the right-angled isosceles triangle E F D. We shall then find that all the points H of the surface D C are pressed by columns of water, G, H, in two different directions, one vertical, the other horizontal; that the first may be expressed by the superficies of the triangle D F C, and the second by that of the triangle D F E; and as these two triangles are in the ratio of their bases F C and F E, since they have the same height F D, we may take their base in place of their superficies, then the vertical pressure will be to the horizontal, as F C to F E, or as F C to F D, since E F = F D.

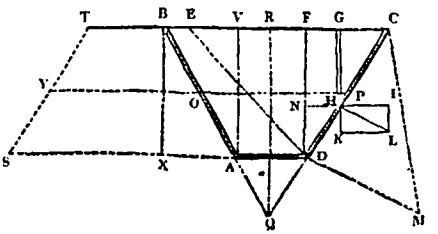


Fig. 1688.

Drawing from the point H the horizontal line H I, and the perpendicular H I to the side D C, making the parallelogram K I, we shall have the similar triangles H I L and D F C, which give D F : F C : : H I : I L. Thus we may take the side I L or H K to express the power which sustains the vertical pressure in equilibrio, and the side H I to express that which sustains the vertical pressure; then the diagonal H L will express the action of a third power in equilibrio with the result of the assemblage of vertical and horizontal pressures.

It follows that the horizontal pressure will be to that which the surface D C sustains, as H I to H L, or as D F to D C; consequently if we raise at the extremity D of the line C D, the perpendicular D M equal to E F, and we draw the line C M, the triangles E F D and C D M, having equal heights, will be in the ratio of their bases D F and D C, or as the horizontal pressure is to the entire pressure which the surface D C sustains. Now as the first

of these pressures is expressed by the superficies of the triangle D E F, the second will then be so by that of the triangle D C M, or, if we wish, by a weight equivalent to that of a prism of water having this triangle for its base and the breadth of the surface of its height.

Since we must, to have the value of the prism, multiply the surface D C by half D M or its equal D F, we find that the rule for measuring the pressure of the water against inclined surfaces is the same as that which we have described for the verticals, since it is reduced to multiply the superficies of the surface by half the height of the water F D: thus all the principles drawn from this rule may be applied to inclined surfaces; for example, if we wish to know what is the pressure of water which acts on the part H D of the surface D C, we must form the point H, draw the horizontal line H N, and multiply this part by the arithmetic mean between F D and F N.

If the vessel S T B A, contiguous to the preceding, were larger above than below the surface, B A will be as much pressed upwards by all the columns which the triangle B X A comprises, which tend to rise to the level T B, as the same surface will be downwards by all the columns contained in the triangle B V A equal to the preceding.

It follows, that if the vessel S T B A only contained water to the height Y O, and the other, A B C D, were full, the opposite pressures which the surface B A would sustain would be as the squares B A and O A, if the surfaces of which these lines express the height have the same base; and as the greatest pressure will be diminished by all the action of the least, that of the water of the vessel A B C D will only be expressed by the difference of these two squares, since it is with inclined surfaces as with vertical.

If the vessel A B C D had the figure of a truncated cone, we must, to have the pressure which all its surface would sustain, multiply the arithmetical mean O P between B C and A D by the side D C, and the product by half the height of the water, F D; if the cone be entire, as B Q C, we must multiply half the circumference, B C, of its base by the side Q C, and the product by half its axis R Q.

It is of the utmost importance that we know how to calculate the pressure which water exerts upon coffer-dams, gates or locks, dykes, banks, &c., in order to proportion the resistance to the effort which they have to sustain relatively to the nature and quality of materials employed.

Having a vessel A B F G whose opposite faces are equal, parallel, and vertical, on filling it with water, all the small columns having the same height will press equally the bottom A D G H, which being sustained by a horizontal fixed plane, M N O Q, will prevent the vessel from descending; on the other hand the opposite surfaces A B C D, H E F G, being equally pressed in a contrary direction by the action of the water, one of these powers not being able to overcome the other, there is no reason why the vessel should be moved to the right or left. The surfaces D C F G and A B E H being in the same state, the vessel, not being able to be moved forwards or backwards, must necessarily remain at rest.

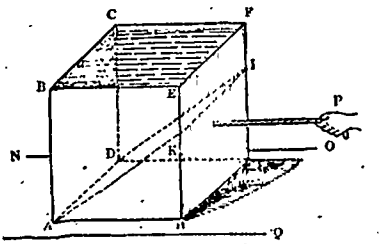


Fig. 1689.

If we cut the vessel obliquely by a plane A I D K, so as not to consider that the water enclosed in the part A B C D, F I K E, which we shall take for a new vessel, placed freely on the inclined plane L M N O, it will happen, independently of the fall which all bodies have in descending along inclined planes which sustain them, that this vessel will have more than if it were filled with a hard body of the same weight, because the pressure which the surface A B C D will sustain is as much greater than that which its opposite K E F I will sustain, as the square of the height B A is greater than the square of the height E K; thus the surface will be pressed in a horizontal direction, with a force which may be expressed by the difference of the same squares; that is to say, for example, that if B A were double E K, it would be pressed by a force equivalent to three-fourths of the weight of the prism of water having this surface for its base, and half B A for its height.

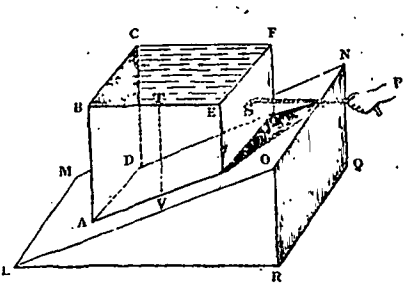


Fig. 1690.

Regard being had only to the action of the weight, it will be indifferent to the power P, which the vessel sustains in a horizontal direction, S P, whether it is filled with a liquid

or a heavy body, since the weight will always be to the power, as the base L R of the plane is to its height R O. Now if we suppose the lines B A, B C, B E, equal to each other, the volume of water which the vessel comprises will be $\frac{3}{4}$ of a cube of the height B A; thus we shall have, as L R, R O : : $\frac{3}{4} \times$ B A^3, P; or $\frac{3\,R\,O}{4\,L\,R} \times B\,A^3 = P$, subtracting the weight of the vessel itself. But since the power must also sustain the difference of pressure against the surfaces B D and E I, or a weight equivalent to the volume of water expressed by $\frac{3}{4}$B A$^3 \times \frac{B\,A}{2} = \frac{3}{8}$B A^3, we shall have $\frac{3\,R\,O}{4\,L\,R} \times B\,A^3 + \frac{3}{8}B\,A^3 = P$.

As for the action of the water on the bottom, A D I K, of the vessel, we see that according to a preceding article, it should be expressed by the product of the superficies of this bottom and of the height T V, the arithmetic mean between B A and E K; but as we are here only speaking of the absolute weight of the water which the same bottom sustains, the preceding product has no relation to the power P.

Resuming the vessel A B F G, which we shall suppose without a bottom, placed on the horizontal plane M N O P Q, as highly polished as possible, so that the base A D G H should be intimately united thereto; filling this vessel with water, the power which will draw it in a horizontal direction will make no more effort to do so than if it were empty, for the vessel having no bottom, this plane will be loaded with the whole weight of the water, whose parts being extremely small will slide without perceptible friction, because all those which might be stopped by the salient parts of the plan would not prevent the columns above from moving horizontally on the surface of a film of water, which would smooth down all obstacles. Thus the only resistance would be the pressure of the edges of the vessel on the plane, which would cause an inexcitable friction, because the parts which would meet, not being fluid, could not be in the same case as those of the water.

It follows that if the preceding vessel were placed without a bottom on an inclined plane, and that the water rested immediately on the plane, the power would only have to sustain the difference of the pressures of the same water against the surfaces A B C D and H K I G in a direction S P parallel to the plane. Thus supposing that A D or H G are 30 inches, A B 20, H K 12, and the height T A of the water 18, we must, to have the power P, begin by seeking the weight of the volume of water which expresses the pressure which the surface A B C D sustains, which will be 218$\frac{3}{4}$ pounds: square the heights B A and K H of the surfaces, take the least square from the greater, say as 400, the square of B A, is to 218$\frac{3}{4}$ pounds, so 256, the difference of the two squares, is to the difference of the pressures, which we shall find 140 pounds, to which we add what is necessary to overcome the friction of the base of the vessel.

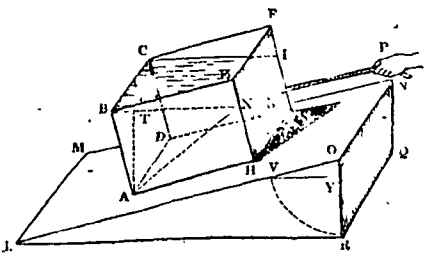


Fig. 1691.

The vessel A B F G having a bottom, or not being placed on an inclined plane, could not contain so much water as if the plane were horizontal, and it would contain as much less water as the inclination is greater; nevertheless, as we suppose that we have only given this position to a power to procure greater facility for elevating water to a given height, O R, the less the inclination of the plane, the greater length it will have, the more time the power would take to draw the vessel from the foot of the ramp to the summit. We are at present contriving to combine the greatest quantity of water which the vessel will contain with the shortest road, so that it shall mount to the height R O of the plane in the least possible time; because, if vessels like this, chained together followed each other with a uniform velocity, it would result that in a determined time, and with a determined velocity, the power would draw from the receptacle, which would be at the foot of the plane, the greatest possible quantity of water in the same time.

The line B K, which marks the level of the water, being parallel to the base L R, the right-angled triangle B E K will always be similar to the triangle L O R. On one hand, without regarding the breadth of the vessel, we may take the trapezium A B K H to express the quantity of water which will be contained in the vessel; drawing the line A K, this trapezium will be divided into two triangles, the first of which, A B K, will always have the same superficies, at whatsoever point of the line E H its summit K abuts, instead of the second A K H, which has for its base the constant line A H, increasing or diminishing in the ratio of its height K H; thus the increase or diminution of the trapezium, or of the water which the vessel will contain at the different inclinations of the plane, may be expressed by the line H K. On the other hand, the time which the power takes to draw the

vessel from L to O, will depend on the length of the road L O, or of the sine of the angle O L R, for the less this sine is with regard to the total sine, the nearer the point K will approach E, and the more water there will be in the vessel, but the road will also be longer; on the other hand, the nearer this sine approaches the total sine, the less water it will hold, but also the length L O approaching more nearly the height O R, the power will take less time to draw it up. Now, since the greatest quantity of water depends on the line K H and the shortest road of the sine of the angle O L R, we see that the product of these two lines should be the greatest of all those which may be formed by the same lines.

Having made O V equal to O R, and drawn from the point V the line V Y parallel to L R, O V may be taken for the total sine, V Y for that of the angle V O R, and O Y for that of the angle O V Y or O L R. Then calling O R or O V, a, O Y, x, V Y will be $\sqrt{aa-xx}$; as for the lines B E and E H, which we suppose equal, as the length is indifferent, we shall express them by unity. Let us consider that the similar triangles V O Y and B K E give

$$\text{V Y}\,(\sqrt{aa-xx}),\ \text{Y O}\,(x) :: \text{B E},\ \text{E K}\left(\frac{x}{\sqrt{aa-xx}}\right);$$

whence we have $\text{E H}-\text{E K}=\text{K H}\left(1-\frac{x}{\sqrt{aa-xx}}\right)$,

which being multiplied by O Y (x) gives,

$x-\frac{xx}{\sqrt{aa-xx}}$, of which we must take the differential, and equal it to zero; we shall have

$$dx-\frac{2xdx\times\sqrt{aa-xx}-x^3\,\overline{dx\times aa-xx}^{-\frac{1}{2}}}{aa-xx}=0,$$

$$\text{or, } aadx-xxdx-2xdx\times\sqrt{aa-xx}-x^3dx\times\overline{aa-xx}^{-\frac{1}{2}}=0;$$

from which effacing the dx we have

$$aa-xx\times\sqrt{aa-xx}-\frac{x^3}{\sqrt{aa-xx}}=0,$$

$$\text{or, } aa-xx-\frac{2aax+x^3}{\sqrt{aa-xx}}=0,$$

$$\text{or, } \frac{x^3-2aax}{aa-xx}=xx-aa;$$

which being squared gives,

$$\frac{x^6-4aax^4+4a^4x^2}{aa-xx}=x^4-2aaxx+a^4;$$

whence we at last have $x^6-\frac{3}{4}aax^4+\frac{3}{4}a^4x^2-\frac{1}{4}a^6=0$;

and if we suppose $x^2=ay$, we shall have $y^3-\frac{7}{4}ay^2+\frac{7}{4}a^2y-\frac{1}{4}a^3=0$, for the simplest equation to which this problem can be reduced.

Since we may suppose the line O R divided into as many equal parts as we please, taking the number 10 to express the value of a, we shall find, according to the ordinary rules, $y=\frac{17}{10}$. To convince ourselves, it is only necessary to multiply the values of a and y in the same manner as in the preceding equation: we shall find $y^3+\frac{7}{4}a^2y=\frac{599913}{1000}$, and $\frac{7}{4}ay^2+\frac{1}{4}a^3=\frac{601150}{1000}$, which showing that the sum of the plusses not differing much from that of the minuses, we may regard them as equal.

Having supposed $x^2=ay$, or $\frac{x^2}{a}=y$, and $a=10$, we shall have $x^2=17$, or $x=\sqrt{17}$: now if we multiply 17 by the square of 10000, which is 100000000, to extract the square root more exactly, it is 41231: on the other hand, multiplying the value of a by 10000, we shall have $a=100000$, which shows that O V (a) should be to O Y (a) as 100000 is to 41231, or nearly as 5 to 2, which is the proportion that may be used in practice. Thus we see that, for the greatest effect, it is necessary that the height O R of the inclined plane should be $\frac{2}{5}$ of its length, L O; then we shall find that the base, L R, of the same plane is to its height, O R, as 23 to 10, or as $4\frac{1}{2}$ to 2.

Taking the side O V (100000) for the total sine, O Y (41231) will make that of the angle O V Y = O L R, which answers in the tables to 24° 21′, which is the angle which the inclined plane should make with the horizon.

On the Action of Water against circular, vertical, and inclined Surfaces.—It remains to show the action of water against circular surfaces, and in what manner we must calculate its pressure, since it is always equivalent to the weight of a volume of water expressed by the parts of a cylinder cut under circumstances relative to the figure and situation of its surfaces.

Let A B C D be a right cylinder cut into two equal parts by a plane E F G H passing through the axis I K, then by another R O B M which forms an ellipsis, lastly by two other planes parallel to the base, forming two circles, of which the first, O L M N, passes through the small axis O M of the ellipsis, and the second, O P V R, through the extremity R of the great axis.

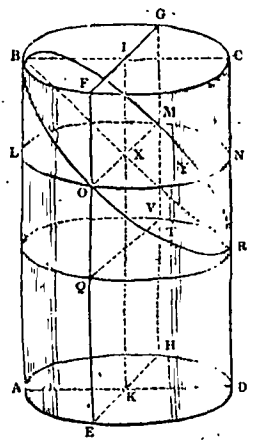


Fig. 1692.

Let us consider that all these sections produce several solids:—firstly, the frustum R O M N R, formed by the semicircles O M N, the semi-ellipsis O M R, and a portion of the surface of the cylinder M Y N R T O.

Secondly; another frustum, O L B M O, equal and similar to the preceding, since it is also formed by the semicircle O L M, the semi-ellipsis O B M, and a portion of the surface of the cylinder O L M B.

Thirdly; the solid R Q O M V R, formed by the semicircle R Q V, the rectangle Q O M V, the semi-ellipsis O M R, and the two portions V M V R V, Q O T R A of the surface of the cylinder: I shall call this solid the complement of the frustum R O M N, because it is the part which is deficient to make the half cylinder Q O M N R V A.

Fourthly; the solid B M R O Q P B, formed by the circle P R, the ellipsis O M B R, and the portion of the cylinder comprised between these two planes.

Fifthly; the solid A B M R D E O B.

Sixthly; the two solids O E A B M H E and O E D R M H E.

If we examine each of these solids in particular, we may consider the frustum O L B M O as composed of an infinity of rectangles D E F C, which would have for their base the double ordinate C F of the semicircle O L M, and for height the corresponding element G H of the right-angled triangle B L X; thus we shall find the sum of all these rectangles in the same manner as we find the solidity of the frustum.

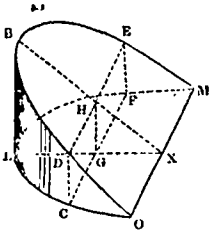


Fig. 1693.

We may also imagine the frustum composed of an infinity of right-angled triangles F H G of an infinitely small thickness, having for base the ordinates F G of the semicircle, and for height the corresponding element F H of the surface: to have the sum of these triangles we shall call the radius D L or D O, a; the height, L B, b; D G, x; G F, y; G, g; K f, dx; F K, dy, and F H, $\frac{by}{a}$.

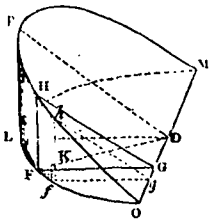


Fig. 1694.

Multiplying the triangle F H G $\left(\frac{byy}{2a}\right)$ by dx, the product will give $\frac{byydx}{2a}$ for the differential solid of the frustum; and as the property of the demicircle gives $a-xx=yy$, substituting the value of yy in the preceding expression, we shall have $\frac{abdx}{2}-\frac{bxxdx}{2a}$, the integral of which is $\frac{abx}{2}-\frac{bx3}{6a}$, or $\frac{aab}{2}-\frac{aab}{6}$. When x becomes a we have $\frac{aab}{3}$ for the solidity of half the solid, consequently $\frac{2aab}{3}$ for the entire solidity, or $\frac{2a3}{3}$ when $a=b$, which shows that in this case the frustum is equal to the third of the cube of the radius.

From what has gone before, we may regard the infinitely small superficies F H fh as the differential rectangle of the surface of the frustum, of whose base we shall have the expression by drawing the radius D F, and considering that the similar triangles F D G and F f K give F G (y) F D (a) : : f K (dx) f F $\left(\frac{adx}{y}\right)$, of which the fourth term being multiplied by F H $\left(\frac{by}{a}\right)$ gives $\frac{byadx}{ay}$, or simply bdx, whose integral is bx or ba when $x=a$ for half the surface of the frustum, consequently $2ab$ for the entire surface, which is found equal to the rectangle comprised by the diameter M O and the height B L of the frustum.

Considering the complement R Q O M V of the frustum as composed of an infinity of rectangles A B C D, which have for their base the double ordinate A D, and for their height the corresponding element E F of the right-angled triangle X Y R, we shall find their sums by subtracting the frustum, which makes the difference from the demi-cylinder Q O M N R V Q. Supposing then $XY=YR=a$, and the half circumference $QRV=b$, we shall have $\frac{aab}{2}$ for the solidity of the demi-cylinder; consequently $\frac{aab}{2}-\frac{2a^3}{3}$, or $\frac{3aab}{6}-\frac{4a^3}{6}$, for the value of the complement of the frustum. Thus the ratio of these two solids will be $\frac{4a3}{3aab-4a^3}$, or $\frac{4a}{3b-4a}$ or $\frac{2a}{\frac{3b}{2}-2a}$, which shows that the frustum is to its complement, as the diameter of the circle, is to the difference between the semi-diameter and three-fourths of the circumference. It follows that if we could find the exact value of the complement of the frustum, we should have the quadrature of the circle.

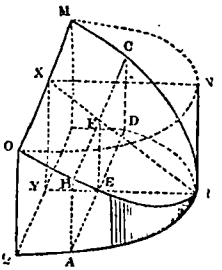


Fig. 1695.

To have in figures the ratio of the frustum to its complement, supposing $a=7$ and $b=22$, consequently $\frac{2a}{\frac{3b}{2}-a}=\frac{14}{19}$, which shows that the frustum is to its complement as 14 to 19.

Considering also this solid as composed of an infinity of planes E, F, G, H, comprised between the double ordinate E H, and the element I K of the triangle P B R, we shall have the sum of all these planes by multiplying the circle P V Q R by the mean element D C, serving as the axis of the cylinder P L N R, because the frustums O L B M and R O M N being equal, the solid we are speaking of will be equal to the cylinder. Cutting this same solid into two parts by the plane Q O M V, which passes through the axis D C, and whose base Q V is perpendicular to the diameter P R, the large piece O Q P B M V will be to the lesser as 47 to 19.

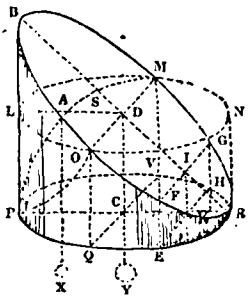


Fig. 1696.

Supposing B P = P R, we shall have B L = L D, and D C = C R; consequently if the frustum O L B M is expressed by 14, its complement O Q R V M will be so by 19; and as these two solids together equal the half cylinder O Q P L M V, it may be expressed by the sum of the preceding two numbers, to which adding that of the frustum, we shall have 47 for the greater part O Q P R M V, and 19 for the lesser O Q R V M.

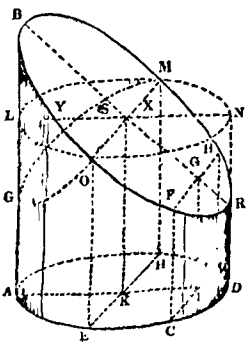


Fig. 1697.

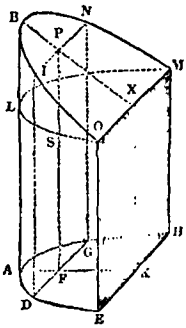


Fig. 1698.

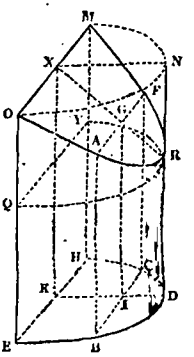


Fig. 1699.

To have the sum of all the planes C F H L comprised by the double ordinate C L, and the element C I of the trapezium A B R D, we must, as in the preceding case, multiply the superficies of the circle A D by the mean element X Y, serving as the axis of the cylinder A L N D, since this cylinder is equal to the solid of which we are speaking.

As for the solids, fig. 1698. and 1699., for the first we shall have the sum of all the planes D I N G by bedding to the solidity of the demi-cylinder A L M H O that of the frustum O L B M, and we shall have that of the second by taking from the cylinder E O M N H D the value of the frustum M N R O.

It will be easy to calculate the pressure of water against all sorts of circular surfaces; for example, if we wish to know that which the superficies of the demicircle A B C sustains, whose diameter A C answers to the level R Z of the water, we remark that in making the right-angled isosceles triangle D B E, all of whose elements represent the heights of films of water, which answer to all the points of the height D B, we shall have the pressure which acts against the double ordinate F G, by multiplying this line by the corresponding element I H. Now as the sum of all these products will be equal to the solidity of a frustum, which would have the demicircle A B C for its base, and the line B E equal to the radius for its height, this pressure will then be expressed by a volume of water equal to two-thirds the cube of the radius D B.

If the demicircle were situated in an opposite direction to the preceding, as K L M, we shall see that since we must, to have the action of all the films of water against the double ordinates O P, multiply each of these lines by the corresponding element Q R of the triangle K L N, the pressure which this demicircle will sustain may be expressed by the complement of a frustum which would have this same demicircle for its base, and the radius for its height. Thus we shall find it by saying 14 is to 19, as $\frac{2\,L\,N}{3}$ is to $\frac{19}{21} \times L\,N^3$, which shows that this pressure is equal to $\frac{19}{21}$ of the volume of water expressed by the cube of the radius. It follows that if the two demicircles are equal, the pressure which the first will sustain, is to that which the second will sustain as 14 to 19.

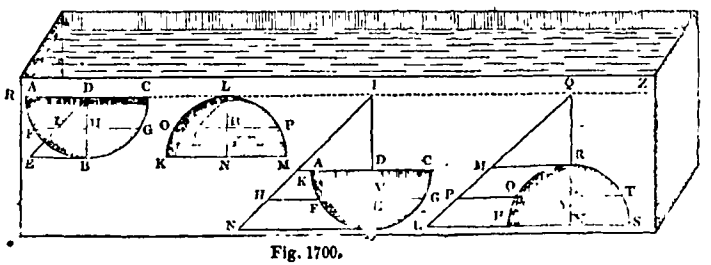


Fig. 1700.

If the two demicircles were below the level R Z, as A B C D and H R S, the lines I B and O X expressing the greatest height of the water, making the isosceles and right-angled triangles I B N and O X L, we must multiply the double ordinates F G and Q T by the corresponding elements H E and P V of the trapezium N K D B and L M R X; then the sum of the products for the demicircle A B C being expressed by a solid similar to that of fig. 1698., we must multiply its superficies by the line D K or D I, which marks the least height of the water, to have the demi-cylinder, and add thereto that of the frustum, that is to say, two-thirds the cube of the radius, we shall have the volume of water whose weight this demicircle will sustain.

As for the other demicircle H R S, as the sum of the products we have been speaking of will be expressed by a solid similar to that of fig. 1699., we see that to have the pressure which it sustains, we must multiply its superficies by the line X L or X O to have the solidity of the cylinder, from which we must subtract that of the frustum, that is to say, two-thirds the cube of the radius.

Lastly, if we have two circles, one of which answers to the level D L of the water, and the other was lower, making the isosceles and right-angled triangles C D B and N L M, the sum of the products of the double ordinates E F, by the corresponding elements G H of the triangle C D B, may be expressed by a solid similar to that of fig. 1696. We must, to have the pressure which the first circle sustains, multiply its superficies by the mean element I K, which is the radius K D, and which marks the height of the water above the centre K.

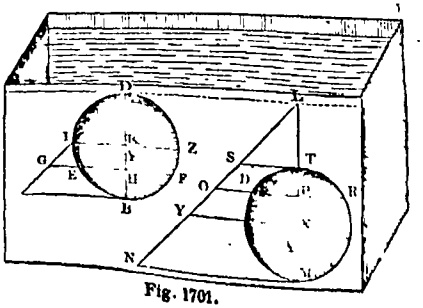


Fig. 1701.

If we recal what has been said, we shall see that the pressure which the lower

demicircle I B Z sustains is to that which the upper I D Z sustains, as 47 to 19

We shall see in like manner that the sum of all the double ordinates Q R by the corresponding elements O P of the trapezium N S T M may be expressed by a solid similar to fig. 1697. To have the pressure which the second circle sustains, we must multiply its superficies by the mean element V X, or its equal X L, which marks the height of the water above the centre X.

It follows that having a tube A B curved below to adapt thereto a species of funnel G E C D F H closed by a piston, pouring the water in this tube to the height K, the power P applied to the piston will sustain a pressure equivalent to the weight of a column of water, which should have the circle E F of the piston for its base, and the line K B which marks the elevation of the level of the water above the centre I for its height, however small the diameter of the tube may be; thus this power will be in the same case as if it were applied to the piston of fig. 1702.

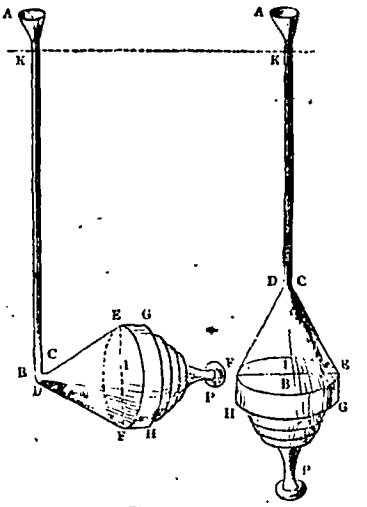


Fig. 1702.

If the preceding surfaces, instead of being vertical, were inclined, all that we have just said would still hold good, having shown that the pressure against both must be measured in the same manner.

It follows, that having an inclined tube A B C D filled with water, and the bottom A D closed by a piston, the power applied thereto will sustain a weight equivalent to that of a column of water having the circle of the piston for its base, and the perpendicular E E, which marks the greatest elevation of the water above the centre E for its height, of whatever form the tube is, without considering its thickness.

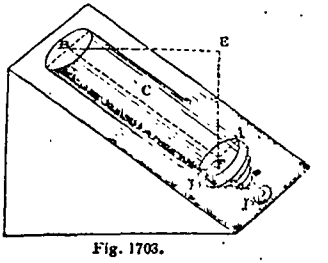


Fig. 1703.

The Centre of Pressure is that point of a surface exposed to the action of a fluid, to which if a force equal to the whole pressure upon a surface were applied, the effect would be the same as when that pressure is distributed over the whole surface. The centre of pressure coincides with the centre of percussion, which is two-thirds the height of the body.

Since the action of all the films of water against a surface A B C D may be expressed by the elements of an isosceles triangle A E D, it is evident that there is a point M in the perpendicular E F, where a power P being applied in the opposite direction, P M, will sustain them all in equilibrio, and if we pay attention we shall see that this point, which is called the centre of impression, can only be the centre of gravity of the triangle A E D; whence it follows that the centre of impression of a rectangular surface A B C D is placed at two-thirds of the line E F, which divides it into equal parts, and marks the height of the water.

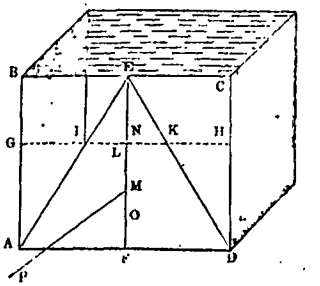


Fig. 1704.

Regarding only the pressure which the rectangle A G H D sustains, which we may apply to a lock gate, the water being always at the same height, E E, the centre of impression of this surface will be the same as the centre of gravity, O, of the trapezium A I D K. To find it let us suppose that the point N marks that of the triangle I E K; then calling E F, a, E L, b, E O, x, we shall have $EM = \frac{2a}{3}$, $EN = \frac{2b}{3}$, $MN = \frac{2a}{3} - \frac{2b}{3}$, and $MO = x - \frac{2a}{3}$.

If, instead of the superficies of the similar triangles I E K and A E D, we take the squares of their perpendiculars, E L and E F, the difference of these two squares, or $aa - bb$

will express the superficies of the trapezium A I K D; thus we shall have

$$aa - bb,\ bb :: \frac{2a-2b}{3},\ x - \frac{2a}{3};$$

whence we have $\frac{2}{3} \times \frac{abb-b^3}{aa-bb} = x - \frac{2a}{3}$, or $\frac{2}{3} \times \frac{abb-b^3}{aa-bb} + a = x$.

If we multiply the magnitude a by $aa-bb$, we shall have $\frac{2}{3} \times \frac{abb-b^3+a^3-abb}{aa-bb} = x$, or $\frac{2}{3} \times \frac{aa-b^3}{a^2-bb} = x$: whence we draw the following general rule.

To have exactly the interval from the Surface of the Water to the centre of Impression of a Lock Gate.—Measure the greatest and least height of the water; cube these two heights; subtract the lesser cube from the greater; take two-thirds of the difference; divide this quantity by the difference of the square of the greatest height of the water from that of the least; the quotient will give the answer required.

If the height E F were 6 feet, and the lesser, E L, 4 feet, subtracting 64 (the cube of 4) from 216 (the cube of 6), we shall have 152 for the difference, of which we must take two-thirds, $101\frac{1}{3}$, which we must divide by the difference of the squares of 6 and 4, which is 20; the quotient will give $5\frac{1}{15}$, that is to say, 5 feet 10 inches nearly, for the interval E O.

As the centres of impression of circular surfaces are the same as the centres of gravity of the solids which express these impressions, and as we cannot have these last centres without knowing that of the frustum, we must examine this solid under a different aspect than before. For this purpose we must consider the solidity of a right cylinder, A B C D, as composed of several surfaces E, F, G, H, of an infinitely small thickness, which pass interseeting from the axis I K to the great surface A B C D; if we imagine that the circle which serves as the base to the cylinder is composed of an infinity of concentric circles, forming as many rings of an infinitely small thickness, each of them will serve as base for the corresponding element of the cylinder. Following this idea, if we cut the cylinder by a plane, M L N D O M, passing through the centre I, and through the extremity, D, of the diameter A D, this plane will detach a frustum, having for its base the semicircle M L C.

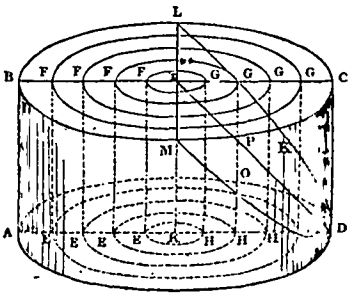


Fig. 1705.

Now, as all the cylinders which pass from the axis to the surface A B C D, have been cut in the same manner as the preceding, each of them furnishing also a frustum, it follows that the largest may be considered as being composed of an infinity of other frustums, similar to each other, all intersecting from the smallest, which answers to the centre, I, to the largest, and similar to each other, because all the triangles I G P will mark their sections through the centre; consequently we may consider the frustum which answers to the great triangle I C D as composed of an infinity of portions of cylindrical, similar, concentric surfaces of an infinitely small thickness, each of which will be equal to the rectangle comprised by the diameter of the demicircle which serves as its base, and by the corresponding element G P of the triangle I D C.

To have the solidity of the frustum in this manner: let A B C be the semicircle which serves for base: describe the semicircles F G E and fge, near each other; call D B or B I, a, D G or G P, x, Gg will be dx; thus we shall have for the differential element of the frustum F E × G P × Gg ($2xxdx$), whose integral gives $\frac{2x^3}{3}$, or $\frac{2a^3}{3}$, when $x=a$, for the solidity of the frustum.

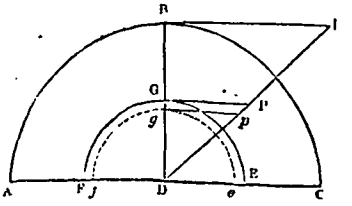


Fig. 1706.

To have its centre of gravity, we must multiply the differential solidity $2xxdx$ by the radius D G (x), which gives $2x^3dx$, whose integral is $\frac{2x^4}{4}$, or $\frac{x^4}{2}$, or $\frac{a^4}{2}$, which being divided by $\frac{2a^3}{3}$, the solidity of the frustum, gives $\frac{3a}{4}$, which shows that the centre of gravity of the frustum is distant $\frac{3}{4}$ of the radius from the centre of its semicircle.

To have the centre of gravity of the complement of the frustum, we only regard the

semicircle VRQ common to these two solids, and the centre of gravity of the demi-cylinder, that of the frustum and that of its complement being in the radius YR, perpendicular to the diameter VQ. We shall suppose that the first is at the point B, the second at the point C, and the third at the point D; on which we must remark that the position of the two first is known, for the semicircle VRQ is to its diameter, VQ, as $\frac{3}{8}$ of the radius YR is to the interval YB: the demi-cylinder being composed of an infinity of semi-circles, all of whose centres of gravity pass through the same line of direction, we may regard all these circles, or the demi-cylinder united in the weight P: on the other hand, as we have the position of the centre of gravity of the frustum, by making YC equal to $\frac{3}{8}$ of the radius YR, we may also suppose its solidity united in the weight T, and that of its complement in the weight S. Considering the point B as the fulcrum of a lever DC, round which the weights S and T are in equilibrio, the first of which is to the second as 19 to 14, we shall have 19 : 14 :: BC; BD = $\frac{14}{19}$ × BC. If we make an angle YCK at pleasure, taking the line CE of any length, it must be divided into 19 equal parts; make EF equal to 14 of these parts, draw the line EB, and through the point F draw a parallel to it, ED, which will give the point D, the centre of gravity of the complement of the frustum, since CE, EF : CB, BD.

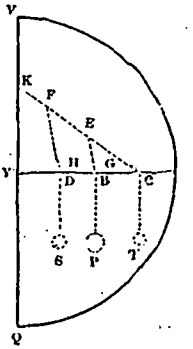


Fig. 1707.

Having a solid, as in fig. 1698., composed of a half cylinder, OEALMH, and a frustum, OLBM, we shall find in the radius AK the point through which the line of direction of the centre of gravity of this solid should pass: for taking the weight P, fig. 1707., for that of the half cylinder, and the weight, T, for that of the frustum, we say, as the sum of the two weights, which is the same as the solid, is to the interval BC, so is the weight T, or the frustum, to the interval BG of the centre of gravity of the half cylinder to that which we seek.

To find it in the same manner, in the radius KD of the base of the solid of fig. 1699., the point through which the direction line of its centre of gravity should pass, we remark that this solid being composed of the demi-cylinder EQVRDH and the complement RQOMV of a frustum, we may, by taking in fig. 1707. the weight P for that of the half cylinder, and the weight S for that of the complement, say, as the sum of these two weights is to the interval DB, so the weight S, or the solidity of the complement of the frustum, is to the interval BH, from the centre of gravity of the frustum, to that of the entire solid.

If in fig. 1696. we take from the cylinder PLNR the equal frustums MN, RO, there will remain the regular solid POMVRQO, whose axis, DC, passing through its centre of gravity, we may suppose this solid united in the weight Y: taking the line DA equal to $\frac{3}{8}$ the radius DL, the centre of gravity of the equal frustums MBLO or MPLO, being at the point A, we may also suppose it united in the weight X: we say, then, as the sum of the weights X and Y, or the solidity of the cylinder PLNR, is to the interval DA, so the weight X, or the sum of the two frustums, is to the interval DS from the centre of gravity LN to the centre of gravity of the solid PBR.

Lastly, we may in the same manner find the centre of gravity of the solid represented in fig. 1697., by subtracting the double frustum OGBM, and making XY equal to $\frac{3}{8}$ the radius, in order to say, as the cylinder ALND is to the interval XY, so is the sum of the two frustums to the interval XS from the centre of the semicircle to the required centre of gravity S.

Specific Gravities of Bodies are determined on the principles of hydrostratics. The diminution of the apparent weight of a solid, upon immersion into fluid, affords us an easy and ready method of comparing its density with that of the fluid: for the weight of the solid being known previous to immersion, it is then ascertained what quantity it has lost when plunged into a body of pure water, by measuring the bulk of water displaced: thus we obtain the proportion of the specific gravity of the body to that of water, which is the usual standard of comparison: for when a solid is weighed in water it will lose as much of its weight as is equal to the quantity of fluid displaced; for bodies so plunged are pressed upwards with a force equal to the weight of the fluid displaced; and as this force acts in opposition to the natural gravity or absolute weight of the body, its absolute weight must be diminished by a quantity equal to the weight of the fluid displaced. The weight which the body loses is not destroyed, but is sustained by an equal and opposite force.

When the specific gravity of a body is equal to that of the water, the part immersed is equal to the whole body; or, it may be said, the solid will be completely immersed, and remain wherever it is placed: when the specific gravity of the body is greater than that of the fluid, it will sink to the bottom, and when the specific gravity of the fluid is greater

than that of the body, then the part immersed is less than that of the whole solid, and the body will float. The specific gravity of the solid is therefore to that of the fluid in which it is weighed, as the absolute weight of the solid is to the loss of weight which it sustains.

In the following table all the measures are related to that of water, whose specific gravity is 1·000. To ascertain the weight of either of the substances contained in the following table, it is only necessary to compare it with the weight of a cubic foot of water, which weighs nearly 1000 ounces avoirdupois, or more nearly 998. Thus a cubic foot of native gold would weigh 170,000 ounces, or 1000 multiplied by 17, its specific gravity: platina, which is one of the densest metals, is 23 times as heavy as distilled water; fine gold 19¼; mercury 13½; lead 11½; silver 11; copper 9; iron and steel 7¾; stone 2½; and fir timber only half the weight.

This method of ascertaining the bulk of bodies was first discovered by Archimedes: but in all experiments made it is necessary to consider that a considerable change of the joint bulk of any two substances tried is often produced by their mixture, and generally their dimensions are considerably contracted. 18 gallons of water, mixed with 18 gallons of alcohol, will make only 35 gallons, and therefore the specific gravity of such a compound is one-thirty-fifth greater than the mean of the specific gravities of the two ingredients: iron also by an addition of one-eighth of its bulk of platina becomes contracted one-fortieth of the whole bulk.

A Table of Specific Gravities.

METALS.	
Antimony, native	6·720
fused	6·624 / 6·860
glass of	4·9464
grey	4·3
sulphur of	4·9643
ore grey and foliated	4·368
radiated	4·440
red	3·750 / 4·090
Arsenic, native	5·670 / 5·600 / 6·522
fused	8·310
bloom	2·640
glass of	3·5942
pyrites	6·5
Bismuth, native	9·570
fused	9·756 / 9·822 / 9·070
sulphuretted	6·131
ochre	4·371
Brass, common cast	7·824
wire drawn	8·544
cast, not hammered	8·395
Cerite	4·5
Cobalt, fused	7·645 / 7·811
ore grey	5·511 / 7·721
earthy black indurated	2·019 / 2·425
vitreous oxide	2·4405
Columbium	5·918
Copper native	7·600 / 7·800
from Siberia	8·5084
from Hungary	7·728
fused	7·788 / 8·895
Copper ores, ore compact vitreous	4·129
Cornish	5·452
Copper, purple, from Bannat	4·956
from Lorraine	4·300 / 4·983 / 5·467
glance	5·6
pyrites	4·080 / 4·344
white	4·500
grey	4·865 / 4·5
yellow	4·3
blue	3·2 / 3·4
foliated florid red	3·950
azure radiated	3·231 / 3·608
emerald	2·850 / 3·300
muriate of	4·4
arseniate, hexaedral	2·549
octoedral	2·88
trihedral	4·2
prismatic	4·2
partial arseniate	3·4
sulphate, solution sat. 42°	1·150
wire	8·878
Gold, native	17·00 / 19·00
pure, fused, 24 carats fine	19·2587
same, hammered	19·342
English standard, 22 carats fine, fused, not hammered	18·888
guinea George II.	17·150
guinea George III.	17·629
Paris standard 22 carats not hammered	17·486
same, hammered	17·589
Spanish coin	17·655
Holland ducats	19·352
trinket standard 20 carats, not hammered	15·709
same, hammered	15·775
Portuguese coin	17·9664
French money 21⅔ carats, fused	17·4022

French money, coined	17·6474
of Louis XIII.	17·5531
Iridium, ore of	19·500
Iron, native meteoric	6·48
fused, not hammered	7·200
forged into bars	7·600, 7·788
chromate from Var	4·0326
from Uralian mountains	4·0579
sulphate sat. solution 42°	1·157
arseniate	3·000
pyrites, dodecaedral	4·830
from Freyburg	4·682
from Cornwall	4·789
cubic	4·702
radiated	4·698, 4·775
magnetic	4·518
white	4·
magnetic sand, Virginia	4·600, 7·800
magnetic	4·200, 4·900
specular ore	4·793, 5·139, 4·939, 5·218
micaceous	4·728, 5·070
Ironstone, red ochry	2·952
compact	3·423
from Siberia	3·760
from Lancashire	3·573, 3·863
compact brown, Bayreuth	3·551
from Tyrol	3·753
cubic	3·503, 3·477
red hematites	5·005, 4·740
brown hematites	3·951, 3·789, 4·029
sparry or calcareous	3·640, 3·810, 3·672
decomposed	3·300, 3·600
black compact	4·706
clay reddle	3·139, 3·931
clay lenticular	2·673
clay, common, from Cathina	2·936
ditto from Roscommon	3·471
ditto from Carron in Scotland	3·205, 3·357
clay uniform iron ore	2·574
pea ore	5·207
Iron, native (Helenchen Mass)	6·723
ore lowland Sprottau	2·944
Lead	11·352, 11·445
arseniate	5·00, 6·40
carbonate	6·00, 7·20
Lead, muriate	6·00
sulphate	6·3
chromate	6·00
acetate	2·3953
vitriol from Anglesea	6·300
glance	7·290
from Derbyshire	6·565, 7·786
compact	6·886, 7·444, 4·319, 5·052
crystallised	7·587
radiated	5·500
from the Hartz	7·448
Kautenbach	6·140
Kirschwalder	5·820
ore, corneous	6·065
reniform	3·920
of black lead	6·745
blue	5·461
brown	6·974
from Huguelgaet	6·600
black	5·770
white from Leadhills	7·236, 6·559
phosphorated from Wanlock-head	6·560
ditto from Zschappau	6·270
ditto from Brisgau	6·941
red lead spar	5·750, 6·027
yellow molybdenated	5·092
Magnesium, sulphate, sat. solution 42°	1·232
native hydrate	2·330
carbonate	2·200
Manganese	6·850, 7·000
grey striated ore of	4·249, 4·756, 4·181
foliated	3·742
red from Kapnich	3·233
black oxide	2·0000, 3·0000, 3·7076
ditto, penetrated by water	3·9039
scaly	4·1165
sulphuret	3·95
white	2·8
phosphate	2·6
Mercury, at 32°	13·619
at 60°	13·580
at 212°	13·375
at 3·42 cent.	13·58597
in a solid state 40° below 0° Fahrenheit	15·612
in a fluid state 40° above 0° Fahrenheit	13·545
native	13·5681
corrosive muriate sat. solution	1·037
natural calx	9·230
precipitate per se	10·871
red	8·399

Mercury, native Ethiops	2·233
Molybdena, saturated with water	7·500
native	4·048, 4·667, 4·7385
Nickel, in a metallic state	7·421, 8·500, 9·3333
copper	6·6086, 6·6481, 7·560
Kupfernickel of Saxony	6·648
ditto of Bohemia	6·607
ditto, sulphuretted	6·620
Osmium and iridium, alloy of	19·5
Palladium	11·8
Platinum	20·722
wire	21·0417
a wedge sent by Admiral Gravina to Mr. Kirwan	20·663
a bar sent by the King of Spain to the King of Poland	20·722
in grains purified by boiling in nitrous acid	17·500, 18·500
native	15·601, 17·200
fused	14·626
purified and forged	20·336
milled and purified	20·98
compressed by a flatting mill	22·069
Potassium at 15° cent.	0·7223
Silver, glance	6·910, 7·200
brittle	7·208
white	5·8
ruby	5·564
light red	5·5886, 5·443
sooty	5·592
native, common	10·000, 10·333
antimonial	9·4406, 10·000
auriferous	10·600
ore, dark red	5·684, 5·5637
arseniated, ferruginous	2·178
same, penetrated with water	2·340
ore corneous, or horn ore	4·7488, 4·804
virgin, 12 deniers fine	10·474
same, hammered	10·510
Paris standard, 11 deniers 10 grains fine, fused	10·175
same, hammered	10·376, 10·784
shilling George II.	10·000
George III.	10·534
French money, 10 deniers 21 grains fine, fused	10·048
same, coined	10·408
Sodium at 15° cent.	0·86507
Steel	7·67
Steel, soft	7·8331
hammered	7·8404
hardened in water	7·8103
hammered, and hardened in water	7·8180
Tantalium metal	5·61
in large masses	6·291
in small pieces	6·208
Tellurium, native	5·700, 6·10
graphic	5·7
yellow	10·6
black	8·9
Tin, pure from Cornwall, fused	7·170, 7·291
fused and hammered	7·291
of Malacca, fused	7·296
same, hammered	7·306
of Gallicia	7·063
of Ehrenfriedendsdorf	7·271
pyrites	4·350, 4·785
stone	6·800, 6·989, 6·750
black tin stone	6·901
red	6·9348, 5·845, 6·970
fibrous	7·000, 5·800, 6·450
new, fused	7·3013
hammered	7·3115
fine, fused	7·4789
hammered	7·5194
common	7·9200
claire etoffe	8·4869
ore, Cornish	5·800, 6·450
from Fahlun	6·55
stone, white	6·008
Tungsten	4·355, 5·800, 6·028, 6·066, 6·015, 5·570
Uranium	7·500
Wolfram	5·705
Zinc, pure and compressed	7·1908
in its usual state	6·862
by sublimation	5·918
sulphate	1·9000
saturated solution	1·386

Woods.

Alder	0·8000
Apple	0·7930
Ash	0·8450
dry	0·800
Bay tree, Spanish	0·8220
Beech	0·8520
Box-wood, French	0·9120
Dutch	1·3280
dry	1·030

Brazil-wood, red	1·0310
Campeachy or logwood	0·9130
Cedar, American	0·5608
wild	0·5608
Palestine	0 5960
Indian	1·3150
Cherry-tree	0·7150
Citron	0·7263
Cocoa-wood	1·0403
Cork	0·2400
Cypress, Spanish	0·6440
Ebony, Indian	1·2090
American	1·3310
Elder	0·6950
Elm	0·6710
Filbert	0·6000.
Fir, male	0·5500
female	0·4980
Hazel	0·606
Jasmin, Spanish	0·7700
Juniper	0·5560
Lemon	0·7033
Lignum vitæ	1·3330
Linden	0·604
Logwood	0·9130
Mahogany	1·0630
Maple	0·7550
Mastic-tree	0·8490
Medlar	0·9440
Mulberry, Spanish	0·8970
Oak, 60 years old, heart	1·1700
Olive	0·9270
Orange	0·7059
Pear-tree	0·6610
Plum-tree	0·7850
Pomegranate	1·3540
Poplar	0·3830
white, Spanish	0·5294
Quince	0·7050
Syringa	1·0989
Walnut, French	0·6710
Yew, Dutch	0·7880
Spanish	0·8070

Earths and Stones.

Actinolite, glossy	2·950 – 3·903
Agalmatolite	2·800
Agate, oriental	0·5901
onyx	2·6375
speckled	2·607
cloudy	2·6253
stained	2·6324
veined	2·6667
Icelandic	2·348
Havre	2·5881
jasper	2·6356
Mocha	2·5891
iridescent	2·5535
Alabaster, Valencia	2·638
veined	2·691
Piedmont	2·693
Malta	2·699
yellow	2·699
Spanish	2·713
Oriental white	2·730
Alabaster, semi-transparent	2·762
stained, brown	2·744
Malaga pink	2·8761
Dalias	2·6110
Allanite	3·119 – 4·001 – 3·533 – 3·665
Alumine, sulphate	1·7140
Amber, yellow transparent	1·0780
opaque	1·0855
red	1·034
green	1·0829
Amethyst	2·750
Ammianthus, long	0·9088
penetrated with water	1·5662
short	2·3134
penetrated with water	3·3803
Ammianthinite, Raschian	2·584
Bayreuth	2·916
Analcime	2·0 – 3·0
Andalusite	3·165
Anhydrite	2·95
Anime, oriental	1·0284
occidental	1·0426
Anthophyllite	3·20
Aplome	3·45
Arcanson	1·0857
Areterite	3·606
Argillite	2·609 – 2·680
Arragonite	2·946 – 2·9267 – 2·94686
Asbestirite	3·000 – 3·310
Asbestos	0·6806 – 0·9933
penetrated with water	1·2492 – 1·3492
ripe	2·5779
penetrated with water	2·6994
starry	3·0733
penetrated with water	3·0808
unripe	2·9958
penetrated with water	3·0343
Asphaltum, cohesive	1·450 – 2·060
compact	1·070 – 1·165
Aventurine, semi-transparent	2·6667
opaque	2·6426
Augite	3·226 – 3·471 – 3·777
Automalite	4·200
Axinite or thumerstone	4·690 – 3·218 – 3·296 – 3·250
Azure stone, lapis lazuli	2·7675 – 2·896
Oriental	2·7714
Siberian	2·9454

Barytes or baroselinite	4·400 – 4·865
white	4·44300
grey	4·4909
rhomboidal	4·4434
octoedral	4·4712
in stalactites	4·2984
sulphate, native	4·000 – 4·460 – 4·48141
carbonate, native	4·300 – 4·338
Basaltes	2·979 – 3·000
from Giant's Causeway	2·864
prismatic, from Auvergne	2·4215
St. Tubery	2·7948
Bdellium	1·1377
Beryl, oriental	3·5491
occidental	2·723
aquamarine	2·650 – 2·759
Bitumen, Judæa	1·104
Black coal, pitch coal	1·308
slate coal, English	1·250 – 1·370
Bielschawitz	1·321 – 1·382
Cannel coal	1·270
Blende, yellow	4·044 – 4·048
brown foliated	3·770 – 4·048
black	3·930 – 4·166
auriferous from Nagyog	5·398
Boracite	2·566
Borax	1·714
Bournonite	5·576
Bronzite	3·20
Calamine	3·525 – 4·100
Carbon, of compact earth	1·3292
Carnelian, stalactite	2·5977
speckled	2·6137
veined	2·6234
onyx	2·6227
pale	2·6301
pointed	2·6120
arborised	2·6133
Cat's-eye	2·600 – 2·625
grey	2·5675
yellow	2·6573
black	3·2593
Cerite	4·500
Ceylanite	3·765 – 3·793
Chabasite	2·718
Chalcedony, bluish	2·5867
onyx	2·6151
veined	2·6059
transparent	2·6640
reddish	2·6645
common	2·600 – 2·655
Chalk	2·252 – 2·657
Chrysolite, jeweller's	2·782
Brazilian	2·692 – 3·340 – 3·410
Chrysoprase	2·489 – 3·250
Cimolete	2·0
Cinnabar, Deux Ponts	7·786
Almaden	6·902
crystallised	10·218
hepatic	7·1
Cinnamon stone	2·6
Clinkstone	2·575 – 2·620
Corundum, Indian	3·710 – 3·875
Chinese	3·981
Cryolite	2·957
Cube iron ore	3·000
spar	2·964
Cyanite	3·517 – 3·622
Cymaphane, Chrysoberyl	3·600 – 3·720
Datolite	2·98
Dipyre	2·63 – 2·84
Diamond, oriental, colourless	3·5212
rose-coloured	3·5310
orange-coloured	3·5500
green-coloured	3·5238
blue-coloured	3·5254
Brazilian	3·4444
yellow	3·5185
orange	3·55
Dolomite	2·800
Emerald	2·673 – 2·683 – 2·600 – 2·723
of Brazil	3·1555
pseudo	2·701
Euclase	3 0625
Felspar, fresh	2·438
Adularia	2·500 – 2·600
Labrador	2·607 – 2·704
glassy	2·518 – 2·589
Fettstein	2·563 – 2·614
Fish-eye-stone, ichthyophthalmite	2·5782 – 2·467
Flint,	2·594
olive	2·6057
spotted	2·5867
onyx	2·6644
Rennes	2·6538
England	2·6087
Limosin	2·2431
veined	2·6122
Egyptian	2·5648
Black	2·582
Gabbronite	2·94

Flint, Gadolinite	4·00 4·20
Garnet, precious, Bohemian	4·085 4·188 4·230 4·352
volcanic	2·468
Syrian	4·000
docaedral crystals	4·0637
common	3·576 3·688
Gehlenite	2·78
Girasol	4·000
Glance coal, slaty	1·300 1·530
Glauberite	2·700
Granite, red Egyptian	2·6541
grey Egyptian	2·7279
beautiful red	2·7609
Girardmor	2·7163
violet of Gyromagny	2·6852
red of Dauphiny	2·6431
green	2·6836
radiated	2·6678
red of Semur	2·6384
grey of Bretagne	2·7378
yellowish	2·6136
Corinthian blue	2·9564
Granitelle	3·0626
Dauphiny	2·8465
Graphic ore	5·723
Gypsum, opaque	2·1679
compact, in Leskean museum	2 939
compact	1·872 2·288
impure	2·473
foliated with limestone	2·725
semi-transparent	2·3062
fine	2·2741
opaque	2·2642
rhomboidal	2·3114
10 faces	2·3117
cuneiform, crystallised	2·3060
striated, of France	2·3057
China	2·3088
flowered	2·3059
sparry opaque	2·2746
semi-transparent	3·3108
granular foliated (Leskean museum)	2·900
slaty, mixed with marl	2·473
Hauym	3·20
Heliotrope, blood-stone	2·629 2·700 2·633
Hollow spar, chiastolite	2·944
Hone, white razor	2·3763
penetrated water	2·8839
white and black razor	3·1271
Honeystone	1·586 1·666
Hornblende, common	3·600 3·830
resplendent Labrador	3·350 3·434
schiller spar	2·882
Hornblende, schistose	2·909 3·155
basaltic	3·150 3·220 3·333
Hornstone, or Petrosilex	2·530 2·653
ferruginous	2·813
veined	2·747
grey	2·654
blackish grey	2·744
yellowish white	2·563
bluish and yellowish	2·626
dark purplish	2·638
greenish white, from Lorraine	2·532
iron shot brownish red	2·813
Hyalite	2·110
Hyacinth	4·000 4·545 4·620
Hyposist	1·5263
Jade, white	2·9592
gum	2·9660
olive	2·9829
from East Indies	2·977
Switzerland	3·310 3·389
with boracic acid	2·566
Jasper, veined	2·6955
red	2·6612
brown	2 6911
yellow	2·7101
violet	2·7111
grey	2·7640
cloudy	2·7354
green	2·6274
bright green	2·3587
deep green	2·6258
brownish green	2·6814
blackish	2·6719
blood-coloured	2·6277
onyx	2·8160
Jasper flowered, red and white	2·6228
red and yellow	2·7500
green and yellow	2·6839
red, green, and grey	2·7323
red, green, and yellow	2·7492
universal	2·5630
agate	2·6608
Jenite	3·80 4·00
Jet	1·2590
Iolite	2·56
Iserine, an oxide of titanium, from Iser	4·500
Lapis nephriticus	2·894
hematites	4·360
judaicus	2·500
monatis	2·270
hepaticus	2·666
Laumonite	2·20
Lenticular ore, arseniate of copper	2·882

Lepidolite	2·816 – 2·854
Leucite, or umphigene	2·455 – 2·490
Limestone, compact	1·3864 – 2·7200
foliated	2·710 – 2·837
granular	2·700 – 2·800
green	3·182
arenaceous	2·742
Lithomarge	2·50
Marl	2·9444
Magnesia, saturated solution of sulphate	1·232
native hydrate	2·330
Magnesite, carbonate of magnesia	2·200
new species from Baumgarten, Silesia	2·95
Malachite	3·572
compact	3·641 – 3·994
Marble, Carrara	2·716
Pyrenæan	2·726
block Biscayan	2·695
Brocatelle	2·650
Castilian	2·700
Valencian	2·710
Grenadian white	2·705
Siennian	2·678
Roman violet	2·755
African	2·708
Italian violet	2·858
Norwegian	2·728
Siberian	2·728
French	2·649
Swiss	2·714
Egyptian green	2·668
Florentine yellow	2·516
Meionite	3·10
Melanite, or black garnet	3·691 – 3·800
Menochanite	4·270 – 4·427
Mesotype	2·233
Mica	2·791 – 2·546 – 2·9342
Muricalcite, crystallised or rhomb spar	2·480
Natrolite, Swedish	2·779 – 2·790
Nepheline, or somnite	3·2741
Nigrine, or calcareo-siliceous titanic ore	3·700 – 4·445 – 4·673
Nitre	1·9000
quadrangular	2·2460
Obsidian	2·348
Octoedrite	3·857
Opal, precious	2·114
common	1·958 – 2·015 – 2·144
semi-opal from Telkobanya	2·540
ligniform, or wood	2·600
Orpiment	3·048 – 3·435
Pearl stone	2·34
Pearls, oriental	2·683
Peridot, or olivine	3·428 – 3·225
Pharmacolite, or arseniate of lime	2·6
Phosphorite or Sporgel stone, without water	2·8249
with water	2·8648
greenish, from Spain	3·098
Saxon	3·218
Phosphorus	1·714
Stone of Volvic	2·320
Pinite	2·980
Pitch ore, or sulphuretted uranite	6·378 – 6·530 – 7·500
Pitchstone, black	2·0499
yellow	2·0860
red	2·6695
brick red from Misnia	2·720
leek green or olive	2·298
pearl grey	1·970
blackish	2·3191
olive	2·3145
dark green	2·3149
Plumbago	1·987 – 2·267
Porcellanite	2·30
Porphyry, green	2·6760
red	2·7651
from Dauphiny	2·7933
from Cordova	2·7542
green, from Cordova	2·7278
hornblende or orphites	2·9722
pitchstone	2·452
mullen	2·600 – 2·728
sandstone	2·564
Potash, carbonate	1·4594
muriate	1·8365
tartrite, acidulous	1·900
antimonial	2·2460
sulphate	2·2980
Potstone	2·80 – 3·00
Prasium	2·5805
Prehnite, of the Cape	2·697 – 2·9423
of France	2·610
Pumice stone, pu	3·9145
Pyenite, or shorlous beryl	3·5145
Pyrope	3·718 – 3·941
Pyrophysalite	3·450
Quartz, crystallised brown and red	2·6468
brittle	2·6404
milky	2·652
elastic	3·750 – 2·6240
Realgar, or red orpiment	3·225 – 3·338

Rock crystal, from Madagascar	2·6530
clove brown	2·605
white from Marmerosh	2·888
European pure gelatinous	2·6548 – 2·63717
Brazilian	2·6526
iridiscent	2·6497
rose-coloured	2·6701
yellow Bohemian	2·6542
blue	2·5818
violet, or amethyst	2·6535
Carthaginian amethyst	2·6570
pale violet	2·6513
brown	2·6534
black	2·6536
Ruby, oriental	4·2833
Brazilian, or occidental	3·5311
spinelle	3·7600 – 3·5700
ballas	3·6458
Rutile	4·102 – 4·246
Rutilite, or sphene	3·1 – 3·5
Sahlite	3·234
Sal gem	2·143
Sapphire, oriental white	3·991
of Puys	4·076
oriental	3·994
Brazilian	3·1307 – 3·994 – 4·283 – 4·000 – 4·083
Sardonyx, puce	2·6025
pale	2·6060
pointed	2·6215
veined	2·5951
onyx	2·5949
arborescent	2·5988
blackish	2·6284
Saussurite	3·260
Scapolite	3·6800 – 3·7000
Schorl, block, prismatic	3·3636
octoedral	3·2265
enneaedral	3·0926
black sparry	3·3852
amorphous, or basaltes	2·9225
cruciform	3·2861
violet of Dauphiny	3·2956
green	3·4529
common	3·092 – 3·150 – 3·212
Selenite, or broad foliated gypsum	2·322
Serpentine, opaque green Italian	2·4295
penetrated by water	2·4729
red and black veined	2·6273
veined black and olive	2·5939
semi-transparent grain	2·5859
fibrous	2·9997
Serpentine, fibrous, from Dauphiny	2·6693
spotted black and white	2·3767
black and grey	2·2645
red and yellow	2·6885
green from Grenada	2·6849
deep green, ditto	2·7097
black, from Dauphiny	2·9883
green	2·8960
yellow	2·7305
violet	2·6424
of Dauphiny	2·7913
Shale	2·6
Siderocalcite	2·837
Sinople	2·6913
Slate, common	2·6718
penetrated with water	2·6905
whet, or novaculite	0·722 – 2·609
Isabella yellow	2·955
stone	2·1861
fresh, polished	2·7664
adhesive	2·080
new	5·8535
siliceous	2·596 – 2·641
horn, or schistose porphyry	2·512 – 2·700
Smalt	2·440
Smaragdite	3·00
Sodalite	2·378
Spar, white sparkling	2·5946
red ditto	3·4378
green ditto	2·7045
blue ditto	2·6925
green and white ditto	3·1051
transparent ditto	2·5644
adamantine	3·873
fluor	3·1555
fluor red, or false ruby	3·1911
octoedral	3·1815
yellow, or false topaz	3·0967
green, or false emerald	3·1817
octoedral	3·1838
blue, or false sapphire	3·1688
greenish blue or false aquamarine	3·1820
violet, or false amethyst	3·1757
violet purple	3·1857
English	3·1796
Auvergne	3·0943
in stalactites	3·1688
pearl or bitter (carbonate, lime, and magnesia)	2·8378
calcareous rhomboidal	2·7151
calcareous rhomboidal in tubes	2·71409
of France	2·7146
prismatic	2·7182
and pyramidal	2·7115

Spar, pyramidal	2·7141
puant gris	2·7121
puant noir	2·6207
or flos ferri	2·6747
Spodumene, or triphane	3·1923 / 3·218
Stalactite, transparent	2·3239
opaque	3·4783
penetrated with water	2·5462
Staurotide, staurolite or gnenatite	3·286
Steatites, of Bareight	2·6149
penetrated with water	2·6657
indurated	2·5834
penetrated	2·6322
Stilbite	2·50
Strontian, sulphate	3·583
carbonate	3·958 / 3·658 / 3·675
Stone sand, paving	2·4158
grinding	2·4129
cutlers'	2·1113
Fontainebleau glittering	2·5616
crystallised	2·6111
scythe of Auvergne, mean-grained	2·5638
fine-grained	2·6090
coarse-grained	2·5686
Lorraine	2·5298
Liege	2·6356
Mill	2·4835
Stone, Bristol	2·510
Burford	2·049
Portland	2·496
Ray	2·470
Ratten	1·981
St. Cloud	2·201
St. Maur	2·034
Notre Dame	2·378
Clicord, from Brochet	2·357
Rock of Chatillon	2·122
hard paving	2·460
Siberian blue	2·945
touch	2·415
prismatic basaltes	2·722
quarry of Baurè	1·3864
of Cherence	2·4682
Sulphur, native	2·0332
fused	1·9907
Sulphuret, triple, lead, antimony, and copper	5·768
Sylvanite, or tellurite in a metallic state, fused	6·343
Sylvan, native	4·107 / 5·723 / 6·115
Sylvan ore, yellow	10·678
black	6·157 / 8·919
Talc, black crayon	2·080
German	2·246
yellow	2·655
white	2·704
of mercury	2·7917
black	2·9004
earthy	2·6325
common Venetian	2·700 / 2·800
indurated	2·90
Tantalite	7·953
Tartar	1·8490
Terra Japonica	1·3980
Titanite, rutulite or sphene	4·102 / 4·246
Topaz, oriental	4·0106
Brazilian	3·5365
Saxon	3·5640
oriental pistachio	4·0615
Saxon white	3·5535
greenish blue	3·5489
red	3·155
Tremolite	2·9 / 3·2
Turbeth, mineral	8·235
Turquoise, ivory stained by blue calx copper	2·500 / 2·908
Ultramarine	2·360
Uran glimmer	2·19
Uranite, in a metallic state	6·440
sulphuretted	6·378
Uranitic ochre, indurated	3·150 / 3·2438
Vermeille, or oriental ruby	4·2299
Vesuvian	3·575 / 3·420
Siberian	3·365 / 3·339 / 3·407
Vitriol, Dantzic	1·715
Wavellite, or hydrayellite	2·7000
Wolf's-eye, mineral	2·3507
Woodstone	2·045 / 2·675
Yttrotantalite	5·130
Yttrocerite	3·447
Zeolite, from Edelfors, red scintillant	2·4868
white scintillant	4·0739
compact	2·1544
siliceous	2·515
Zinon, or jaryon	4·615 / 4·666 / 4·700 / 4·3858 / 4·4161
Zirconite	4·24
Zoizite	3·26 / 3·31

CHAP. XVII.

THE THEORY OF THE MOTION OF FLUIDS.

The Theory of the Motion of Fluids necessarily follows the consideration of the laws which relate to their equilibrium: both Daniel Bernouilli and Huygens supposed that no force is lost in the communication of motion between different bodies considered as belonging to any system; and that they always acquire such velocity in descending through any space, that the centre of gravity of the system is capable of ascending to a height equal to that from which it descended, notwithstanding a mutual action between the bodies: an elastic ball, for instance, weighing 10 ounces, descending from the height of a foot upon another of 1 ounce, in such a manner as to lose the whole of its motion, the smaller ball will acquire a velocity capable of carrying it to the height of 10 feet. These laws with certain restrictions are applicable to the motion of fluids.

We are indebted to Archimedes for the first theory upon floating bodies; he established the principles that the parts of a liquid least pressed are impelled by those which are more so, and that each part is always pressed by the weight of its corresponding column; also, that a body impelled by a fluid is driven in a vertical direction through its centre of gravity: such were the established laws with regard to fluids upwards of two thousand years ago, since which time a third principle has been discovered, viz. equality of pressure in every direction, that is, if a pressure be applied to any point on the surface of a fluid, it is equally transmitted to all other points in that liquid.

On the Measurement of Waters which flow through Tubes or Reservoirs. — To establish the principles which are the object of this proposition, we must remark that the portions of water enclosed in the vessel press mutually in every direction with equal forces in each horizontal bed; and that if any escape by an opening made in the bottom, all other portions with which it is surrounded hasten to flow on this side with a certain gradation of velocity, dependent on the force of those which follow, or on the weight with which they are loaded. Now as the force which presses on the surface of the water to make it descend may be regarded as nothing, with respect to the pressure sustained by the film which serves as the base of a column of water answering to the orifice, we cannot say that it is this column which escapes, and is continually renewed by the surface, but that generally all contained in the vessel rushes to the orifice.

To make this clear, suppose a vessel A B C D filled with water to the height I K, if we plunge a tube E F G H open at both ends to the bottom, its surface will be pressed in horizontal directions with equal and opposite forces, intersecting according to the order of the terms of an arithmetical progression. For tracing on the sides E F, G H of the tube the right-angled and isosceles triangles F E S and G H T, their elements will represent the action of the water against the outer surface. As the point X will be pressed with a force expressed by the element V X, and the point Y opposite to the preceding with a force expressed by the height F Y equal to V X; and it will be the same with all the other points taken in the same horizontal bed L M; we find that the water of the vessel will make as much effort to enter the tube, as that in the tube will to escape.

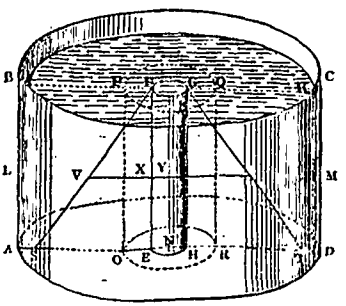


Fig. 1708.

As the extent of the base A D is indifferent to the pressure of which we have been speaking, it will be seen that if the vessel were itself a tube, O P Q R, a little larger than that in which it is plunged, the surface of the latter will always be pressed with the same force, however small the difference between the two circles O R and E H, provided their circumferences do not join.

If the middle tube be suppressed, so as only to regard the column enclosed therein, the surface will be pressed by the water with which it is surrounded with the same force as that of the tube was: to know the ratio of this force relatively to the action of the weight of the column on the bottom of the vessel, let r be the radius, N H, of the circle

E H, c its circumference, and h the height E F of the water. Thus we shall have $\frac{hhc}{2}$ for the pressure which the surface sustains, and $\frac{rhc}{2}$ for its weight; whence we have $\frac{hhc}{2}, \frac{rhc}{2} : h, r$, which shows that the effort made by the water of the vessel to occupy the place of the column, is to the inclination of this column to descend, as its height is to the radius of its base. Hence we may conclude that when the height of the column exceeds its semi-diameter, the portions of the water which compose it can never escape altogether by an opening equal to its base, because the force with which it will tend to descend will be less than that of the water which seeks to replace it: thus showing that during the time of flowing the column will always have the same weight, since the parts which escape will instantly be replaced by others.

It follows that when water in a vessel is continually maintained at the same level, that which escapes by an orifice made in the bottom will always have the same velocity, since it will be driven by the whole weight of the column, which presses it, and which we may regard as a constant force acting uniformly on the whole extent of the orifice.

The same will not take place with water in a straight tube, which voids itself by an opening equal to the base, because it falls in one piece, like a cylinder of glass, that is to say, that in issuing it has at first a very slight velocity, which increases like that of heavy bodies, from the instant of its fall. As the water of the column is not replaced either from the top or sides, its surface answering immediately to that of the vessel, it is in the position of all heavy bodies, and consequently follows the law of their accelerations, not meeting any circumstance which can cause a change in its fall. The time which such a tube would take to empty itself totally will be equal to that required by a body in descending freely through the same space which the upper surface of the water goes over in the tube.

Since we can always render a retarded or accelerated velocity uniform, by taking half the great velocity, we may apply the rule when we wish to compare the expenditure of a tube such as the preceding with that of another always maintained full.

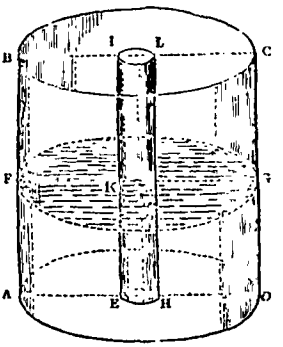


Fig. 1709.

Fig. 1709. If the surface of the water contained in a tube or reservoir, after having remained during a certain time at the same level B C, was then at the level F G, notwithstanding the expenditure through the orifice E H in the bottom of the vessel: its uniform velocity in the first case would be to its uniform velocity in the second, as the square root of the height I E is to the square root of the height K E.

Fig. 1710. When in two reservoirs of different heights, the orifices O, O are unequal in superficies; the small prisms of water which issue therefrom in the same instant may be expressed by O V and $o u$, because they can only have for base that of the columns which impel them, and for height the space which a film detached from the same columns may go over with a uniform motion in this instant. As these spaces will be in the ratio of the velocities exercised in the same instant, the velocities may hold the place of spaces, since in this case the question is only of the ratio of these prisms. As the columns of water which the orifices would expend in two different times T, t, will contain as many times the small prisms O V, $o u$, as the number of instants that elapse in the duration of time T, t, we shall have $\frac{M}{T} = OV$, and $\frac{m}{t} = ou$; whence we have $\frac{M}{T}, \frac{m}{t} : OV, ou$, which gives $\frac{M ou}{T} = \frac{m OV}{t}$, or $M otu = m OTV$, or a general formula comprising the masses or quantities of water, their velocities, the time of their flowing, and the size of the orifices; that is to say, all the circumstances which enter into the measurement of the water.

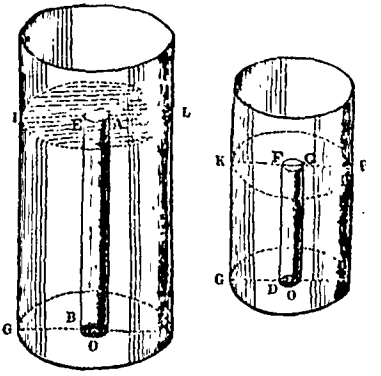


Fig. 1710.

To facilitate the calculations upon the expenditure of water, Belidor has furnished some excellent tables relative to the uniform velocity of the falls during a second of time, constructed in arithmetical progression. The parabola A D C, the axis of which, A B, is supposed to be 15 feet, and its greatest ordinate, B C, 30 feet, was the figure adopted: the ordinates E F, G H, &c., express the expenditure at the several heights.

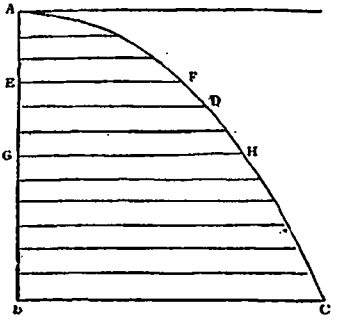


Fig. 1711.

For the quantity of water discharged over a *weir* Mr. Eytelwein represented the velocity, which varies as the square root of the height, by the ordinates of a parabola, and the quantity of water discharged by the area of a parabola two-thirds of that of the circumscribing rectangle: hence the quantity of water discharged may be found by taking two-thirds of the velocity due to the mean height, and allowing for the contraction of the vein.

On the Manner of estimating the Waste caused by the Edges of Orifices. — As water flows more swiftly towards the centre than at the edges of orifices, being retarded by the friction they occasion, less will issue from an orifice during a specified time, than would be the case if all the threads had uniform velocity; consequently the expenditure stated in the preceding calculations is greater than in actual experience, and this difference increases as the orifices become less, because the circumferences of circles being to each other as the diameters, while their superficies are as the square of these diameters, the small orifices, having more circumference in proportion than large ones, the velocity of water with relation to its quantity will be proportionably retarded.

To find this ratio, we must take the squares of the diameters for the superficies of the orifices, and the sides of these squares as their circumferences: thus calling a the diameter of the lesser, and b that of the greater, we shall have $\frac{a}{aa}$ for the ratio of the circuit of the first to its superficies, and $\frac{b}{bb}$ the ratio of the circuit of the second to its superficies, which reduces it to $\frac{1}{a}$ and $\frac{1}{b}$; whence we have $\frac{1}{a}, \frac{1}{b}$; b, a, since $\frac{a}{a}=\frac{b}{b}$, or $ab=ab$, which shows that the ratio of the circuit of the first to its superficies, is to the ratio of the circuit of the second to its superficies, as the diameter of the second, to the diameter of the first.

It follows that the ratio of the decrease of the first orifice to its natural expenditure will be to the ratio of the decrease of the second to its natural expenditure, as the diameter of the second is to the diameter of the first. By natural expenditure it must be understood that which is found by rule, without considering accidental circumstances, and by waste, the excess of the natural expenditure above the effective, found by experiment.

When the ratio of the waste to the natural expenditure of any orifice is determined by experiment, we shall have the ratio for any other orifice thus: as the diameter of the given orifice, is to the diameter of that of the experiment, so the ratio of the waste to the natural expenditure found in the experiment, is to a fourth term, which will give that required.

M. Mariotte states in his "Traité du Mouvement des Eaux" that he has proved by a number of experiments that from a horizontal orifice, three lines in diameter, 13 feet above the surface of the water, 14 pints or 28 lbs. issued in one minute.

Let the circle A B represent an orifice, divide its diameter at the point C in the ratio of the effective expenditure to the waste: calling A B, a, and C B, b, the square D B (aa) will express the natural expenditure, the rectangle F B (ab) the decrease, and the rectangle D C ($aa-bb$) the effective expenditure. In like manner, calling d the diameter of another orifice, dd will express its natural expenditure, and as the decreases are to each other in the ratio of the diameter, we shall have $a, d : ab, bd$; whence we have $dd-bd$ for the expression of the effective expense of the second orifice.

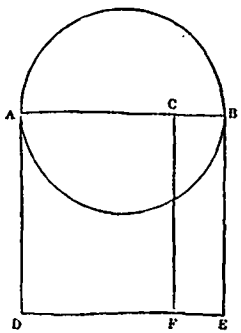


Fig. 1712.

If we take $aa-ab$ and $dd-bd$ to express the ratio of the two orifices, and Mm to express that of their expenditure, we shall have $M, m : aa-ab, dd-bd$, when the times are equal, and the reservoirs the same height. Calling V the velocity of the water at the orifice, whose expenditure is expressed by M and T, the time of flowing, u the velocity of the water of the second reservoir, whose expenditure is expressed

by m, and t the time of flowing, we shall have $M, m : \overline{aa-ab} \times TV, \overline{dd-bd} \times tu$, since the expenditures are in the compound ratio of the orifices, the times, and the velocities; whence we have $\overline{aa-ab} \times TVm = \overline{dd-bd} \times tuM$, which formula will give that of the four required dimensions d, m, t, u.

If we wish to ascertain the diameter of the orifice of a reservoir whose height or velocity is given, in order that it may effectually expend in a given time a determined quantity of water, designated by m, taking the mean of all the other quantities comprised in the formula, we shall substitute a for d, to have $\overline{aa-ab} \times TVm = \overline{xx-bx} \times tuM$, which will be reduced to $\frac{1}{2}b + \sqrt{\frac{bb}{4} + \frac{TVm}{tuM} \times (aa-ab)} = x$.

If the diameter of the orifice, the height of the reservoir, or the velocity of the water, and the time are given, and we require the effective expenditure, we must substitute x in place of m, to have $\overline{aa-ab} \times TVx = \overline{dd-bd} \times tuM$; whence we have $x = \frac{dd-bd}{aa-ab} \times \frac{tuM}{TV}$.

If the diameter of the orifice, the effective expenditure, and the times are given, and we wish to know the velocity of the water per second, in order to deduce the height of the reservoir, we must put x in place of u, to have $\frac{aa-ab}{dd-bd} \times \frac{TVM}{tM} = x$.

When similar quantities have the same value, we must efface them from the formula, which will render the calculation more easy. For example, it is required what diameter should be given to the orifice of a reservoir, 13 feet high, in order that its effectual expenditure per minute may be quadruple that of M. Mariotte; as we have $T = t$, $V = u$, and $\frac{M}{m} = \frac{4}{1}$, the equation will be changed into $\sqrt{\frac{4aa-4ab}{1} + \frac{bb}{4}} + \frac{b}{2} = x$, having $a = 3$ lines, $b = \frac{9}{10}$, and $\frac{b}{2} = \frac{9}{20}$; making the calculation we shall find that the diameter required should be nearly $5\frac{1}{2}$ lines instead of 6, which appeared to be that required.

To show that the orifice just found will effectively expend quadruple that of the experiment; as 9 (the square of the diameter of 3 lines), is to $30\frac{1}{4}$ (the square of the diameter just found, $5\frac{1}{2}$ lines), so 4 lbs. of water (the natural expenditure of the first orifice), is to the natural expenditure of the second, which will be $13\frac{4}{9}$ lbs. To subtract the waste, multiply the denominator $\frac{8}{9}$ by the diameter $5\frac{1}{2}$, we shall have $\frac{8}{55}$ for the ratio of the waste to the natural expenditure: then, as 55 is to 46, so $13\frac{4}{9}$, the natural expenditure of the second orifice, is to its effective expenditure, which will be $11\frac{2}{3}$ lbs., a number quadruple 28; that is to say, the effective expenditure of the first orifice, neglecting the four ounces arising from the diameter having been estimated at a little more than it ought, by supposing $\frac{48}{160} = \frac{1}{3}$.

We shall have with geometrical precision the required diameter by constructing the equation $\sqrt{4aa-4ab+\frac{bb}{4}} + \frac{b}{2} = x$. For this purpose we must draw the line A B equal to $2a$; prolong it from B to C, so that B C may be equal to $2b$; describe on A C as a diameter the semicircle A D C; elevate the perpendicular B D, whose square will be $4ab$; raise also on the extremity A the perpendicular A F equal to $\frac{b}{2}$; draw the line F B, whose square will be $4aa + \frac{bb}{4}$; describe on this line the demicircle B H F; make B H equal to B D; then draw the line F H, which must be prolonged from F to G by the length F A; then the line G H will be exactly the diameter required, since we shall have

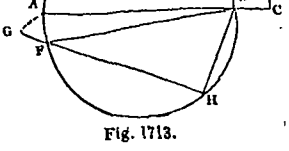


Fig. 1713.

$$\sqrt{FB^2\left(4aa+\frac{bb}{4}\right) - BH^2(4ab) + GF\left(\frac{b}{2}\right)} = GH(x).$$

Of whatever figure the orifices may be, whether similar or not, their natural expenditure being always in the ratio of their superficies, and the wastes in the ratio of their circuit, it follows that when the superficies are in the ratio of the circuits, the natural expenditure will be as the decreases, and this happens when one of two orifices is a circle, and the other the square of its diameter; for calling d the diameter, and c the circumference, $\frac{cd}{4}$ will be the

superficies of the circle, and $4d$ the circuit of its square; whence we have $\frac{cd}{4} : dd\,C, 4d$, which shows that the ratio of the waste to the natural expenditure of a square orifice three lines square may further be expressed by $\frac{9}{10}$. Thus when we wish to know the proportion for any square orifice, we must multiply the denominator of $\frac{9}{10}$ by the side of the square reduced to lines; for example, for a square of an inch, we shall have $\frac{9}{10 \times 12}$, or $\frac{3}{40}$.

On the Measurement of the Water flowing through rectilinear and vertical Orifices. —

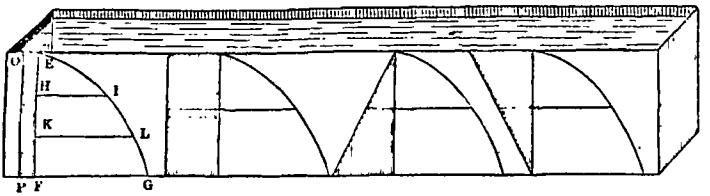


Fig. 1714.

It has been demonstrated that a prismatic vessel continually filled with water has each of its faces pressed in a horizontal direction by the films of water which it sustains; consequently, if this surface be pierced with several holes, H, K, &c. in the vertical E F, the water in issuing will be driven in horizontal directions, with velocities which may be expressed by the roots of the heights E H and E K, or by the corresponding ordinates H I and K L of a parabola E I G, since the property of this curve gives $\sqrt{E\,H}$, $\sqrt{E\,K}$: H I, K L. Supposing the perimeter of this parabola 60 feet, the ordinates H I and K L will express, not only the ratio of the velocities of the water, but also the real velocities per second of the threads which issue through the small holes H and K: then knowing the heights E H and E K in feet, inches, and lines, we shall have, by the assistance of the first table, the values in feet, inches, and lines of the ordinates H I and K L.

It follows, that if all the threads of water which issue through one of the orifices H or K have the same velocity, the natural expenditure per second will be equal to a column which would have for its base the plan of the orifice, and for height the ordinate which answers to it.

If we suppose the axis E F of the parabola E L G divided into an infinity of equal parts, they will compose an infinite arithmetical progression, or the smallest term of which will be zero, and the greatest the height E F of the water, which will express at the same time the number of terms of this progression. Drawing through each point of the division an ordinate H I or K L, beginning from the summit E, all these ordinates being in the ratio of the roots of their abscissæ, or those of the terms of the progression of the parts of the axis, the sum of all these roots will be found in the same manner as those of the ordinates which compose the superficies of the parabola, by multiplying the axis E F by two-thirds the greater ordinate F G. We shall have also the sum of all the roots of the corresponding abscissæ, or that of all the terms of the progression, by multiplying the axis E F by $\frac{2}{3}\sqrt{E\,F}$, or $\sqrt{E\,F}$ by $\frac{2\,E\,F}{3}$.

To demonstrate the same rule, independently of the parabola, let us consider the right-angled isosceles triangle E F G, whose height E F being taken for that of the water, all the elements M N will compose the terms of the preceding progression, or all the different heights of the water, taken from its level to the bottom of the vessel. To have the sum of the roots of all these elements, call F F, h; E M, x; thus M m will be dx, which being multiplied by $\sqrt{x}$ will give $dx\sqrt{x} = x^{\frac{1}{2}}dx$ for the sum of the roots comprised in the differential plane M m N n, the integral of which gives $\frac{2}{3}x^{\frac{3}{2}}$, or $\frac{2}{3}x \times \sqrt{x}$, or $\frac{2}{3}h \times \sqrt{h}$, when x becomes equal to h.

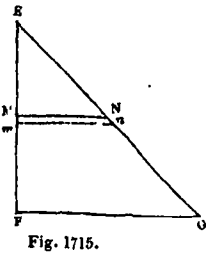


Fig. 1715.

If a fluid, according to Mr. Vince, issues from a cylindrical or prismatic vessel whose horizontal section is everywhere the same, and in which the fluid is always maintained at the same height, the orifice will discharge twice the quantity contained in the vessel, in the same time that the vessel would have emptied itself. As the surface of the fluid is uniformly retarded, and as its velocity becomes nothing at the bottom, the space which the descending surface would describe with the first velocity, continued uniform during the time that the vessel takes to empty itself, is twice the space that the surface really describes in the time in which the vessel empties itself: in this time, therefore, the quantity of fluid discharged in the former case is twice that which

is discharged in the latter, as the quantity discharged when the vessel is kept full may be measured by what would be the descent of the surface, if it could descend with the velocity with which its descent commences.

When a vessel A B C D is pierced at the bottom and the water is only maintained at the height G H, it does not, in issuing out, always entirely fill the hole D F, but leaves a void in the middle, forming a funnel M I Q L O P, which gives place to a circular jet, whose total expenditure per second is equal to a volume of water, comprised by the hole E F, the height I K, and the line which expresses the velocity acquired by a fall $\frac{8}{9}$ of the height I K.

This jet only issues when the sum of the velocities of the water tending to replace that of the column in the middle is less than the uniform velocity of the same column.

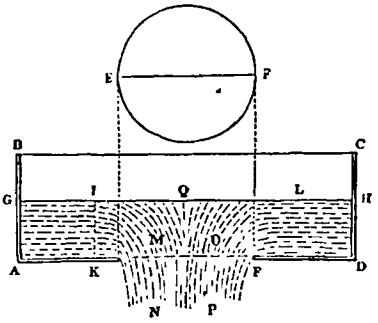


Fig. 1716.

When a horizontal orifice N O is at the extremity of a curved tube E P L M, the height I Q of the surface G H of the water, with regard to the diameter of the orifice, is of no consequence, because the curved part T P V M L of the tube being filled, the air which answers to the level G H cannot issue through the orifice; but although the water be maintained at the level G H, its velocity will not always be expressed by the root of the height I Q, because the diameter of the orifice N O, that of the valve X Y, the height I Q, and the height I K of the level of the water above the bottom A D of the reservoir, may be such that the water may not be sufficient for the orifice: for whatever be the height of the line I Q, the reservoir will not furnish more than can issue by the hole X Y; and for the jet to act fully it is necessary that the square of the diameter N O of the pipe, and the root of the height I Q of the level of the reservoir above this pipe, should be at least equal to the product of the root of the height G A or I K of the water in the reservoir multiplied by the square of the diameter X Y; that is to say, these four should be reciprocally proportionate.

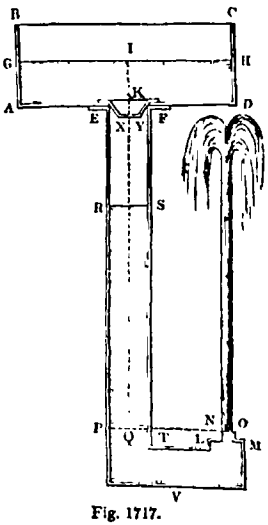


Fig. 1717.

It is therefore not surprising that reservoirs considerably elevated above the issue pipe frequently form jets of little height, and very short of the proportion which they should have; for the passage of the water on the grating being always much less than the circle of the conduit pipe prevents the tube from being always full, and keeps the water at one height, R S, because the grating will only furnish a certain quantity which will cause the expenditure of the orifice to be relative to $\sqrt{R P}$, and not to $\sqrt{I Q}$.

When the summit of a rectangular orifice is above the level of the water, as M K L N, the sum of all the velocities of the films of water which issue from it may be expressed by the elements of the parabolic segment F H I G, and there will be a mean, O T, which being multiplied by the height H F will give a product equal to the superficies of this segment. As the portion of this element will determine the mean height E O, the following method may be adopted.

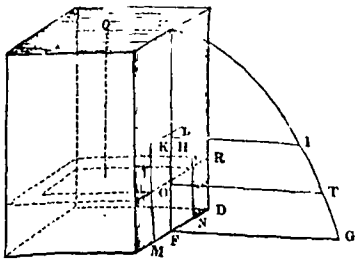


Fig. 1718.

Calling E F, a; E H, b; H F, c, and the mean height E O, x, the sum of all the velocities of which the films in the height E F are capable will be $\frac{2a}{3}\sqrt{a}$, and the sum of all the velocities of the height E A will be $\frac{2b}{3}\sqrt{b}$; consequently $\frac{2a}{3}\sqrt{a}-\frac{2b}{3}\sqrt{b}$ will give the sum of all the velocities issuing from the orifice, which being equal to the product of the mean velocity,

$\sqrt{\text{E O}}, (x)$, multiplied by the height H F, (c), we have $\frac{2a}{3}\sqrt{a} - \frac{2b}{3}\sqrt{b} = c\sqrt{x}$, which being squared gives $\frac{4}{9}a^3 - \frac{4}{9} \times 2ab\sqrt{ab} + \frac{4}{9}b^3 = cc x$, or $\frac{4}{9} \times \frac{a^3 + b^3 - 2ab\sqrt{ab}}{cc} = x$; whence we have 9, 4 : : $\frac{a^3 + b^3 - 2ab\sqrt{ab}}{cc}$, x, or, 9 is to 4, as the sum of the cubes of the greatest and least height of the water relatively to the orifice, minus twice the square root of the product of these two cubes, the difference divided by the square of the height of the orifice, is to the mean required.

If the height E F (a) be 8 feet, the height E H (b) 6, the height H F (c) will be 2 feet; we shall then have 512 for the first cube, and 216 for the second, the product of which gives 110592, from which extracting the square root we have $332\frac{11}{20}$, twice which is $665\frac{1}{10}$, which being subtracted from 728, the sum of the two cubes, there remains $62\frac{9}{10}$, which divided by 4, the square of the height of the orifice, gives $15\frac{29}{40}$ for the third term of the proportion: then as 9 to 4, so is $15\frac{29}{40}$ to the height required, which will be 6 feet 11 inches $10\frac{2}{3}$ lines.

Another and more simple method of finding the mean velocity of water from a rectangular orifice is to seek the velocities which answer to the greatest and least height of the water; multiply each of these velocities by its fall, subtract the second produet from the first, take $\frac{2}{3}$ the difference, and divide this quantity by the height of the orifice; the quotient will give the required velocity.

When the orifices are trapeziums whose sides B C, A D, are parallel, having their summits at the level of the water, the expenditure of the first will be obtained by multiplying two-thirds of the rectangle E B C F, plus two-fifths the sum of the triangles A E B, F D C, by the greatest velocity of the water; and the expenditure of the second by multiplying two-thirds the rectangle B E F C, plus four-fifths the sum of the triangles A E B, F D C, by the greatest velocity.

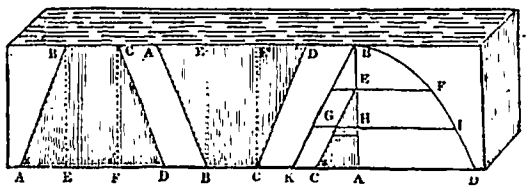


Fig. 1719.

If the two triangles C E A in figures 1719. and 1720. do not answer to the level of the water, the summit of the first and the base of the second being below the summit B of the parabola, multiply the elements of these triangles by the corresponding ordinates of the parabolic segment A E F D. Calling the perimeter of the parabola p, A D, a, the base C A or C E, b, B E, c, E A, h, B A, n, E F, q, E H, x, H I, y, we shall have, on account of the similar triangles, $h, b : x, \frac{bx}{h} = \text{GH}$, which being multiplied by ydx gives $\frac{bxydx}{h}$ for the differential of the solid; and as we have $pc + px = yy$, or $x = \frac{yy - pc}{p}$, whose differential is $dx = \frac{2ydy}{p}$, putting the values of x and dx in $\frac{bxydx}{h}$ will give $\frac{2by^4dy - 2pbcyydy}{pph}$, whose integral is $\frac{2by^5}{5pph} - \frac{2bcy^3}{3ph}$; and putting in place of y^5 and y^3 their value will give $\frac{2b}{5h} \times \overline{c+x}\sqrt{\overline{pc+px}} - \frac{2bc}{3h} \times \overline{c+x}\sqrt{\overline{pc+px}} = \frac{2b}{5h} \times (c+x)^2\sqrt{\overline{pc+px}} - \frac{2bc}{3h} \times \overline{c+x}\sqrt{\overline{pc+px}}$; and supposing $x = 0$, there remains $\frac{2bcc}{5h}\sqrt{pc} - \frac{2bcc}{3h}\sqrt{pc} = -\frac{4bccq}{15h}$, which being added with the contrary sign gives $\frac{2b}{5h} \times \overline{c+x}^2\sqrt{\overline{pc+px}} - \frac{2bc}{3h} \times \overline{c+x}\sqrt{\overline{pc+px}} + \frac{4bccq}{15h}$.

When x becomes equal to h, we shall have $c + x = n$, and $\sqrt{\overline{pc+px}} = a$; therefore, by substituting these values, we shall, after reducing the terms to the same denomination, have $\frac{b}{15h} \times 6ann + 4ccq + 10acn$, for the most simple expression of the solid; so that to have the expenditure of a triangular orifice whose summit is below the level of the water, we must first multiply the greater velocity, A D, by six times the square of the height B A of the water; secondly, multiply the least velocity, E F, by four times the square of the height, B E

of the level of the water above the summit of the orifice; add these two products together; thirdly, multiply the greater velocity, A B, by ten times the rectangle comprised by the whole height, B A, of the water, and by the part, B E, which marks its level above the summit of the orifice; subtract this latter product from the sum of the two preceding, multiply the difference by the base, C A, of the orifice, and divide this last product by five times the height, E A, of the orifice.

On the Measurement of Water flowing through vertical and circular Orifices.—The solid under consideration must be regarded as formed by the sum of the products of the elements of a semicircle, and by the corresponding ordinates of a parabola, because the diameter of the semicircle being vertical, this solid will be exactly half that which expresses the discharge of the entire circle: given a semicircle A E B, and a semi-parabola A F D, whose axis is the diameter A B; required the solid formed by the sum of all the planes comprised by the elements, L P, of the semicircle, considered as the breadth of the planes of water, and by the corresponding ordinates P M, which express the velocity of these planes during a determinate time; by calculation we find that the solid is $\frac{16}{15}$ of the parallelepipedon comprised by the square of the radius and the greater ordinate, or, which is the same thing, $\frac{4}{15}$ of the parallelepipedon comprised by the square of the diameter and the greater ordinate: therefore, to have the entire discharge per second through a circular orifice whose summit is on a level with the water, take $\frac{8}{15}$ of the product of the square of the diameter, multiplied by the velocity of which a body is capable per second, and which it has acquired by a fall equal to the diameter of the orifice.

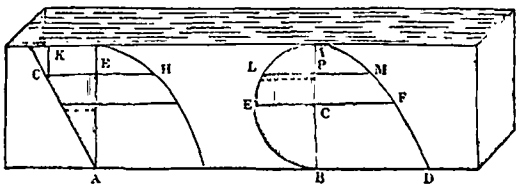


Fig. 1720.

To have the discharge from an orifice in the form of a quarter circle, as A E C, multiply the square of the diameter by four times the velocity, B D, answering to the extremity of the same diameter; subtract from this product that of the square of the radius, multiplied by 14 times the velocity of the centre, and $\frac{1}{15}$ part of the difference. The square B D being twice C F, B D will be to C F as the diagonal of a square to its side, or nearly as 7 to 5; wherefore the discharge of the upper quarter circle is $\frac{2}{3}$ the volume of water, which has the square of the radius for its base, and the greatest velocity during the time of flowing for its height, and the discharge from the lower circle is two-thirds the same volume; thus these two are as 5 to 3.

To find the discharge from a quarter circle whose diameter is at the level of the water, multiply the square of the radius by half the greatest velocity of the water during the time of flowing, and by the entire velocity if that of a semicircle be required: in the first case the fall is the radius, and in the second the diameter of a circle; thus the two velocities are nearly as 7 to 5, or, by more accurate calculation, when two equal semicircles are disposed as F K H and P L M, the expenditure of the first is to that of the second in equal times, as 25 to 28.

To find the discharge per second from a vertical and circular orifice above the level of water, multiply the least height, E A, of the water by 29, and divide the product by 37 for a first quotient; multiply the diameter of the orifice by 18, and divide the product by 85 for a second quotient: cube the diameter of the orifice, and divide the cube by the product of 72, multiplied by the square of the least height of the water for a third quotient; square the diameter of the orifice, and divide the product by 28 times the least height of the water for a fourth quotient: subtract the fourth from the sum of the three other quotients; multiply their difference by the product of the square of the diameter of the orifice multiplied by 60; divide this product by the velocity acquired by a body in a fall equal to the least height of the water; the quotient will be the expenditure required.

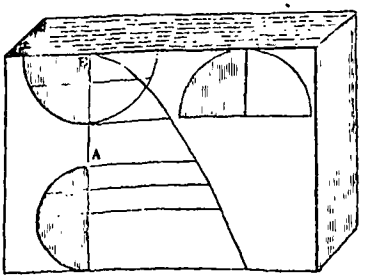


Fig. 1721.

On Fluids flowing through Orifices under a constant Pressure.—At the bottom of a vessel *a b c d*, is a horizontal orifice, *g h*, through which the liquid contained in the vase flows out: required the quantity that will flow out under a constant given pressure *e m*. To resolve this question, adapt the given vessel to a reservoir A B D C, whose height, A C, is less than

that of a column of liquid which measures the atmospheric pressure. The reservoir is inclined on all sides, only communicating with the external air by the tube *em*, which is open at the two ends, and whose lower extremity, *e*, is in a horizontal plane drawn through a given point *l*: the reservoir and the vase *abcd* being full, if the orifice *gh* be opened, the liquid will flow through it, and sink below the bottom, *cd*, of the reservoir; at the same time the atmospheric air will enter by the tube *em*, and replace the liquid: the point *e* of the bed, *ef*, of the liquid supports the atmospheric pressure, each of the points of the same bed supporting an equal pressure, there being two variable pressures, owing one to the elastic force of the air, more or less diluted, which presses the upper surface of the liquid, the other to the height of the liquid above the same point; whence it follows that the liquid contained in the reservoir will flow through the orifice *gh*, under a constant pressure, *em*, as long as the level of the liquid is above the bed *tef*.

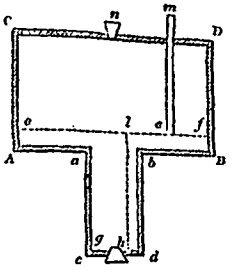


Fig. 1722.

To refil the reservoir shut the orifice *gh*, open the top or stopper placed on the upper part of the reservoir; after having filled it shut the stopcock, and again open the orifice *gh*.

Of the lateral Communication of Motion in Fluids when at rest.—Venturi, Professor of Natural History at Modena in 1798, gave an account of his investigations on this subject, and was almost the first of modern philosophers who turned his attention to it. To prove that the motion of a fluid is communicated to the lateral parts which are at rest, he introduced the horizontal cylindrical pipe A C into the vessel D E F B, filled with water as high as D B; opposite, and at a small interval from the aperture C, was the commencement of a small rectangular channel of tinned iron, S M B R, open at the top, S R, the inclined bottom M B resting on the edge of the vessel B. The breadth of the channel was 24 lines; the diameter of the tube A C 14½; it was inserted in a reservoir, and the water kept at a certain height; when the water of the reservoir was permitted to flow through A C, the current rose along the channel M B, and rushed out of the vessel, producing a current B V in the vessel D E F B; the fluid was carried into the channel S R, and issued at B along with the water in the reservoir; in a few seconds the water, D B, fell to M H.

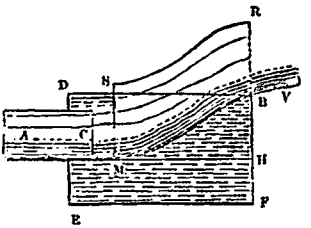


Fig. 1723.

Light bodies placed near a stream of water issuing from a reservoir exhibit a similar effect; they are impelled by the air which descends with the stream. The lateral parts of a fluid by these experiments are proved to be carried along with any stream that flows through it, and consequently the motion is communicated to the lateral parts, which are at rest. This principle Venturi applied to explain the theory of the water-blowing machine, and also to show that the eddies in rivers are caused by the motion communicated from the more rapid parts of the current to the lateral and tranquil portions: he also exhibited a method of draining a piece of ground on a lower level than the current, which has been tried with some success, by means of a fall of water without the aid of machinery: when a vessel is filled with a fluid, and is at rest, or in equilibrio, all the particles of the fluid are equally pressed in every direction; but when a small hole is made at the bottom or in the side of the vessel, the fluid immediately over it will descend by the force of its own gravity.

In a vessel allowed to empty itself by a hole at the bottom, the surface of the fluid preserves its level state until it comes to within half an inch of the bottom, when a funnel-shaped cavity appears on the surface; when it issues from a hole in the side of the vessel, it preserves its level until lowered to the upper edge of the hole, when it inclines a little, and assumes a hollow form. The particles of a fluid move towards the hole in directions which converge to a point outside the orifice, so that the column of fluid which issues from the vessel must have a smaller diameter than the orifice itself; Sir Isaac Newton, who first observed this effect, called it the vena contracta, or the contraction of the fluid vein. The distance from the orifice, where the greatest contraction takes place, is equal to half the diameter of the hole; and the area of the section of the vein at this place is to the area of the orifice, as 10 to 14·14 according to Newton, or 10 to 16 according to Bossut, who also noted that with a short cylindrical tube, applied instead of a mere aperture, the vena contracta was to that of the orifice as 10 to 12·8.

The pressure of the atmosphere increases the expenditure of water through a simple

cylindrical tube, when compared with that which issues through a hole in a thin plate, whatever may be the direction of the tube; this Venturi has proved upon the principle of vertical ascension combined with the pressure of the atmosphere, a heavy fluid moving in a descending cylindrical pipe accelerating its motion: the lower particles have a tendency to separate themselves from the upper, and thus cause the pressure of the atmosphere to increase the velocity of the upper; this cannot take place in an ascending or horizontal pipe, though the pressure of the atmosphere in such cases increases the velocity of the fluid within the pipe. In descending cylindrical tubes, the upper ends of which have the form of the vena contracta, the velocity of the effluent water corresponds with the height of the fluid above the lower extremity of the tube. A descending tube applied to a reservoir increases the expenditure, as was remarked by Frontinus, *De Aquæduct*, "Calix devexus amplius rapit."

Let B L K O be a conical tube having the form of the vena contracta, the cylindrical tube L C Q K having the same diameter as the contracted part L K; the fluid stratum L K continuing to descend through the height L C, will have its motion accelerated in the same manner as all other bodies falling by the force of gravity: hence, when it passes from L K to L M it tends to detach itself from the stratum immediately above it, or, in other words, to produce a vacuum between L K and M N, and the same effect is produced through the whole length, L C, of the tube: the pressure of the atmosphere becomes active as far as is necessary to prevent the vacuum, and its action is the same both at A, the surface of the fluid, and at C, the lower extremity of the tube; the atmospherical pressure at A increases the velocity of the fluid, which issues at C Q, while at C it destroys the sum of the accelerations, which would be produced along L C, so that the fluid remains continuous in the tube.

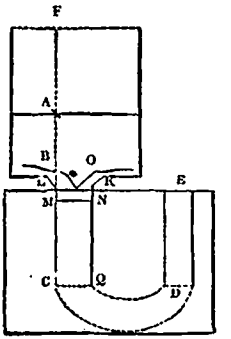


Fig. 1724.

Let t represent the time in which the continuous column of fluid L C Q K passes through the tube L C, whatever be the velocity at L, and the successive acceleration from L to C; if we suppose this column to return upwards from D to E, it will pass through the space D E, which is equal to L C in the same time t, during which it will lose all the acceleration it acquired in its descent from L to C: the pressure of the column E D continued during the time t is therefore the force necessary to destroy the successive acceleration from L to C, and to prevent the fluid from losing the continuity in the tube L C; hence it follows that the pressure of the atmosphere, which is exerted at C Q to destroy the sum of the accelerations along L C, is equal to the pressure of a column E D of a fluid of the same nature as that of the reservoir from which the water flows; and since the same pressure must also be exerted on the surface A of the reservoir, if we take F A = L C, the fluid at L K will possess the velocity which is proper to the height F L = A C, without considering the retardation produced by the internal inequalities of the tube L C Q K. It is supposed by Hachette that the cause of this increased expenditure by tubes is the adhesion of the fluid to the sides of the tubes, which results from capillary attraction.

On the Shock of Water against Plane Surfaces. — The shock or impetus of a column of water is in the compound ratio of the bases of the columns and the square of the velocity of the water, or their falls: wherefore, when the bases of the columns are equal, the impacts will be to each other as the squares of the velocities of the water, or as the heights of falls capable of the same velocities. When the bases of the columns are equal, and they strike equal surfaces, the water may be considered as a mass of small spheres whose impact will depend on their velocity, and the number which strike at the same time: for a portion of water flowing with twice the velocity of another portion, striking a surface opposed to it not only with twice its force, but with twice its number of particles, its impetus must increase in the double proportion, or as the square of its velocity, that is, if the velocities are as 3 to 5, the shocks will be as 9 to 25. The shocks being to each other as the product of the orifices multiplied by the heights of the water, or as the columns B R and F S, in fig. 1725., which are the forces causing the impacts, it follows that the impacts may be measured by the weight of the same columns, since the effect of a force acting simply without modification may be taken for the force itself. As the pressure which the columns B R and F S exercise on their base is nothing more than a tendency to motion whose effect would be to produce a shock, which may be measured by the cause itself, it follows that the weight which will express the pressure of water on a surface will express the impact also.

The difference produced by friction between the natural and the effective discharge from the same orifice of a medium size will also be very great in the effect of impact, because the impacts being in the double ratio of the velocities, the impression of the effective will be as much less than that of the natural discharge, as the square of the velocity of the first will be less than that of the velocity of the second.

If the surface G H, in fig. 1726., be placed at a certain distance E I from the orifice E, the water in escaping, acquiring a new degree of velocity in going through the space E I, will

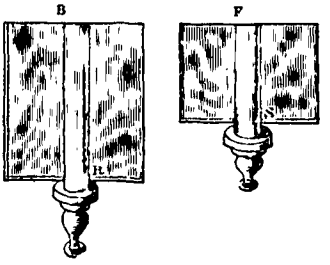


Fig. 1725.

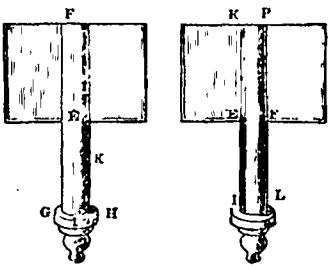


Fig. 1726.

give a greater shock than in the preceding case, because its velocity will then be expressed by the root of its height F I; whence it has been imagined that the impact should be equal to the weight of a column having the orifice E for its base, and the line F I for its height, without remarking that, although the velocity of the water does really increase, yet the quantity which would leave the reservoir would be always the same, at whatever distance the surface might be situated; thus a greater force has been calculated on in working machinery than really existed.

Another supposition was that, if the water were directed by a pipe I E F L, its impact might be expressed by the weight of a column I K P L, but it is not possible that this tube should fill perfectly, since, whatever its length, the velocity of the water at its issue would always be greater than at its entrance; consequently a column could not be formed without being increased by the acceleration, unless it were so narrow that its velocity would be more retarded by friction than it could be increased by the acceleration; for the water in the reservoir being alone capable of maintaining the column E K P F, that in the tube not being replaced by the sides, its discharge could not be greater than that of the orifice which fed it.

When the velocity of the impact of water is accelerated, it is equal to the weight of a column having for its base the surface struck, and a mean proportional between the height of the water in the reservoir and the line which expresses the elevation of its level above the surface struck for its height; consequently the greater the interval between the surface and bottom of the reservoir, the more power will be gained to work a machine, showing that the only advantage to be drawn from the tube E L is to direct all the water towards the surface, and prevent it from being dissipated in passing through the air.

If a prismatic reservoir B C D E be continually filled with water, and a rectangular orifice F G H I be made in one face E C, serving as the entrance to a canal whose bottom and sides are composed of rectangles F I X S, I H V X, F G T S, and a power R sustaining a vertical surface N O M Q equal to the rectangular aperture, and this be suddenly opened, the immovable surface will be struck by a force equal to the pressure which sustained the sluice when the aperture was closed; that is to say, the impact will be equal to the weight of a prism of water, having the surface struck for its base, and the mean height L K between L*a* and L*b* for its height. This is evident, for the velocity of the water in the canal being uniform, and

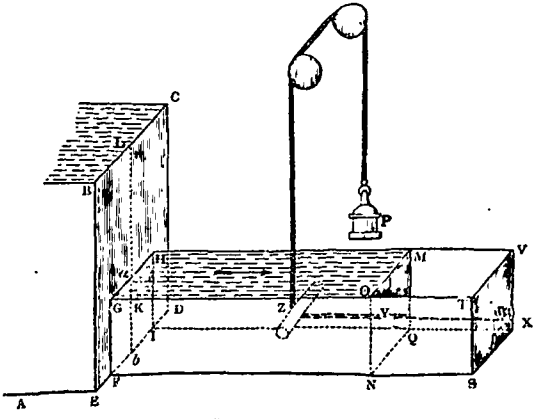


Fig. 1727.

expressed by the root of the mean height L K, the impact will be equal to the product of this surface multiplied by the square of $\sqrt{LK}$, or, which is the same thing, by L K itself: consequently, if the opposite surface contained 4 square feet, and the mean L K 10 feet, the impact would be equal to the weight of 40 cube feet of water, or about 3150 lbs., which is the force required by the power R to support in equilibrio the impulse of a

current whose mean and uniform velocity per second will be equal to that which a body would acquire in falling from the height L K.

As the threads of water of the current increase in velocity in approaching the bottom of the canal, their impression on the surface will diminish as they approach the summit O M in an arithmetical progression, since these impressions will be the same as those of the pressure sustained by the sluice of the aperture when closed: if the surface in question be represented by the float-board of a wheel, it would be necessary to know its centre of impression, because the arm of the lever which corresponds to the mover must always be expressed by the distance from this centre to the axis of the wheel.

A body rolling or sliding on a highly polished inclined plane B C D E acquires in descending from the summit to the base the same velocity which it would have acquired in falling from the height B A of the same plane. Hence, water at rest allowed to run down an inclined plane would acquire a velocity which may be expressed by the root of the height of the plane. If a reservoir be placed at the summit of an inclined plane, the water which issues from F G H I, having already a velocity expressed by the root of the mean height L K, or its equal M N, will acquire a greater, expressed by $\sqrt{MA}$, after having gone over the inclined plane; but as

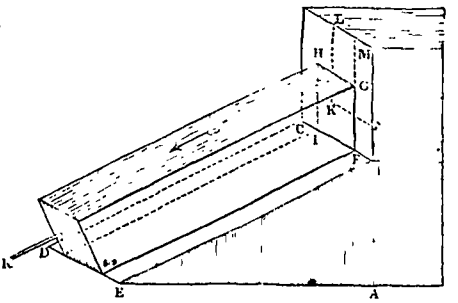


Fig 1728.

the volume of water which issues from the aperture each instant will always be expressed by $\odot \sqrt{MN}$, whatsoever be the height of this plane, calling $\odot$ the aperture, the quantity of motion, or the shock of the water, will be expressed by $\odot \sqrt{MN} \times \sqrt{MA} = \odot \times \sqrt{MF \times MA}$, which shows that if there be at the foot of the inclined plane a surface equal to the aperture which receives the impression of the water directly, the power R, which sustains this surface in equilibrio, will be equal to the weight of a prism of water having a plane equal to the aperture for its base, and the mean proportional between M N and M A for its height.

Whatever may be the dimensions of a surface, to measure the impact or shock, the part which receives the impression must alone be taken into the calculation: if the water in issuing from the bottom or one of the faces of a reservoir flows over several contiguous inclined planes, without meeting any other obstacle than the planes themselves, its direct impulse against a surface, relatively to the height of the water in the reservoir, will be the same as that of a solid body under similar circumstances.

When the direction of a current is not perpendicular to the opposing surface, it does not act with its absolute force. Suppose, for example, that the line N O represents the base of a vertical surface placed obliquely to a current at the bottom of a canal, and that P V expresses the velocity and direction of the current; it is evident that if this surface be impressed by a solid body, the impression will be expressed by the perpendicular P T. But as the object under consideration is a fluid whose impression must be measured by the square of the velocity, its absolute weight will bear the same proportion to its respective force, as the square of P V to the square of P T, that is, as the square of the total sine, to the square of the sine of the angle of incidence.

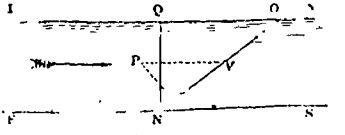


Fig. 1729.

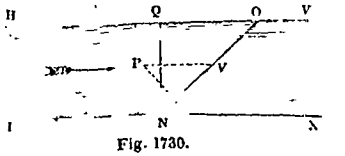


Fig. 1730.

Suppose the line N Q to represent the base of a surface directly opposed to the current, as it will be perpendicular to the side I X of the canal, the parallels Q O and P V will give the similar triangles Q N O, T P V; then calling N Q, a, N O, b, P V, m, P T, n, we shall have $aa, bb : nm, mm$, which gives $aamm = bbnn$, and $amm, bnn : b, a$. As the first term of this proportion expresses the product of the surface N Q, multiplied by the square of the entire velocity of the current, and the second that of the surface N O by the square of this modified velocity, the impulse which the direct surface sustains, is to the impulse which the oblique surface sustains, reciprocally as the length N O is to the length N Q. If the surface N O be inclined, and have the same base as Q N directly opposed to the current, the line H V representing the level of the water, the impulse sustained by the

vertical surface will be to that sustained by the inclined surface reciprocally as the breadth N O to N Q.

When an immovable surface is directly opposed to a current, the power sustaining it will be equivalent to the weight of a column of water having this surface for its base, and the mean height of the reservoir for its height. Now if in the interval K Y (fig. 1727.) a roller Z be placed, which traversing the canal can turn freely on gudgeons, having two pulleys above, it is evident that if a cord be attached to the centre Y, passing over the roller, and thence over pulleys, with a weight P equal to the impulse of the current, this weight will take the place of the power R, and sustain the surface N O M Q in equilibrio, as before; but if it be diminished, the surface will be driven forwards with a velocity equal to that of the weight in ascending, since there is no difference between the arms of the levers; the impulse of the current will be diminished precisely by the same quantity as the weight was, since these two forces will always be equal. When the weight P is diminished by a certain quantity, the surface of the fluid acquires the greatest velocity of which it is capable, and preserves it constantly uniform while the weight mounts, and the impulse which presses it will be expressed by the square of the excess of the velocity of the current over that of the surface.

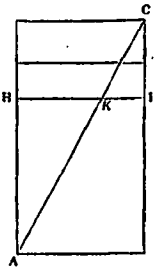


Fig. 1731.

Since among all the elements of a rectangle there is always one which can be divided by the diagonal A C, in such a manner that the square of the greater part H K multiplied by the lesser K I gives the greatest of all the products that can be formed, it follows that the entire velocity of a current may be divided into two parts, the smaller of which becoming that of the surface, and the other that with which it is struck, this surface will have the greatest possible quantity of motion. It is ascertained that the velocity of the surface should be one-third that of the current for the greatest effect; that is to say, that it may at the same time receive the greatest velocity and impression possible, the combination of which answers to the greatest quantity of motion, the force of the shock being equal to $\frac{4}{9}$ the weight of the column of water which measures the absolute force of the current against the surface when it is immovable. In a state of equilibrium the quantity of motion of the mover is always equal to that of the weight, and for the greatest effect we can only count on $\frac{1}{3}$ of the moving power; it follows that it can only raise $\frac{4}{9}$ of the weight with which it was in equilibrio when acting in full force.

If the aperture F G H D be closed, in fig. 1727., and the water comprised in the space F G M Q be at rest, leaving the weight P out of the question, the power which will drive the surface N O M Q with a uniform velocity in the direction R Y will be the same as that which would be necessary to support this surface in equilibrio against the impact of a current which would have the same velocity; for whether the water meets the surface, or the surface the water, the impact will always be expressed by the square of their respective velocities.

If the surface meet a current issuing from an aperture, the power having to support not only the impulse of which the velocity of the current may be capable, but further that which arises from its own velocity, the resistance resulting from their concussion must be expressed by the square of the sum of the velocities of the surface and current; that is, if the current have a velocity of 3 feet per second, and the surface in ascending passes over 2 feet in the same time, it would be the same as if it supported in equilibrio the impression of a current whose velocity was 5 feet per second, or as if it were driven with this velocity in still water; for if, when a surface retreats from a current, its velocity must be subtracted from that of the current, to obtain the velocity with which it is struck, it is natural, when the surface meets the current, to add the velocity of the former to that of the current: on the other hand, when the same surface is moved in the natural direction of the current, with a velocity greater than the impulse which the power sustains, it should be expressed by the square of the difference between the velocity of the surface and that of the current, because the surface is then relatively to the water which retires, what the current is when the surface retires from its impact.

M. de la Hire first started the idea that the uniform velocity of running water may be regarded as acquired by a fall, consequently as the mean velocity which the water from a reservoir would acquire whose height would be equal to this fall; whence he concludes that the direct impression of a current against a vertical surface should be measured by the weight of a column of water having for its base the surface struck, and for its height the fall relative to the velocity of the current.

If the surface retreat from the current, we shall, in like manner, find the impulse which it sustains, by subtracting its velocity from that of the current, if the first is less than the second, or by subtracting the velocity of the current from that of the surface, if it be the contrary, and by dividing the square of the difference by 60, to have the height of the prism

of water. But when the surface meets the current, we must add their velocities together, and divide the square of the sum by 60.

When the force which moves the surface of water at rest is given, and it is required to find what velocity that force will produce; first find the height of a prism of water having the same surface for its base, and whose weight would be equal to the given force; then seek the velocity relative to a fall equal to the height of the prism, which will be that required.

If the force given move a surface against a current, first seek, as in the preceding case, the velocity answering to the height of the prism of water, regarding it as the sum of the velocities of the current and of the surface, from which subtracting that of the current, the difference will be the velocity with which the surface will remount.

To find the Velocity of a Current, the rough method was formerly adopted of throwing a piece of wood into the water, and observing the space which it went over in a certain time; to effect this more accurately, M. Pitot invented an instrument consisting of two glass tubes open at the ends; the first, A B, is straight, and the second, C D, has one extremity curved and funnel-shaped, E F G D; the whole is enclosed in a prism of wood to preserve it from accident. The tube is divided into equal parts, like a barometer, expressed in inches and lines, and is plunged perpendicularly into the water, so that the entrance to the funnel may be opposed to the direction of the current, in order that it may enter the funnel; the water then rises in the two tubes, but at different heights. The line H I represents its level: it can only rise in the first, A B, to the height G B, which dips in the water, having only its weight to compel its rise, while the water which enters the curved tube C D will rise to a height M K proportionate to the velocity of the current, which, being considered as acquired by a fall of a certain height, the water will ascend to the same height, and be sustained there by the impulse of this velocity, which, acting on the entrance, D E, of the tube, will be in equilibrio with the weight of a column M K. Care must always be taken to direct the funnel in the most rapid thread of the water, remarking the point where it rises highest, without regarding whether this thread be straight or oblique: if it sometimes happen that an eddy makes the water rise above the level corresponding to its velocity, after some little time it will assume its natural level: a still day should also be selected, as the wind prevents it rising to its proper height.

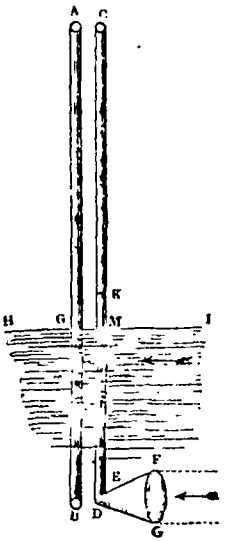


Fig. 1732.

Motion of Water in Conduit Pipes and open Canals. — M. Eytelwein observes that a head of water may be divided into two parts, the one employed in producing velocity, the other in overcoming friction, and that the latter height, employed in overcoming the friction must be directly as the length of the pipe and the circumference of the section, or as the diameter of the pipe, and inversely as the content of the section, or the square of the diameter, viz. on the whole inversely as the diameter; this height must also vary, like the friction, as the square of the velocity.

To determine the velocity of the discharge of a pipe, when the height of the water in the reservoir above the point of discharge, and the length and diameter of the pipe, are given: multiply 2500 times the diameter of the pipe in feet by the height in feet, and divide the product by the length in feet, and add 50 times the diameter; the square root of the quotient will be the velocity of the discharge in feet per second. Suppose the diameter of the pipe to be ·375 feet, the height of the water in the reservoir above the point of discharge 51·5 feet, and the length of pipe 14637 feet: then

$$\frac{2500 \times \cdot 375 \times 51 \cdot 5}{14637 + 50 \times \cdot 375} = \frac{48281 \cdot 25}{14655 \cdot 75} = 3 \cdot 3,$$

the square root of which is 1·816, the velocity in feet per second.

To determine the quantity of water a pipe will discharge when the height of the reservoir above the place of discharge, the length of the pipe, and the diameter are known, multiply the area of the pipe in feet by the velocity in feet, as found by the above rule, and the result will be the discharge in cubic feet per second.

If from these rules the equation for the quantity discharged be formed, and that quantity be called Q, we have $Q^2 \left(\frac{l + 30d}{1542h}\right)^5$, from whence the diameter of the pipe to supply a given discharge may be found.

On the Quantity of Water discharged by Orifices of different Forms from Vessels kept constantly full.—In making these experiments M. Bossut employed very clear water running through holes made in plates of copper half a line in thickness; the temperature of the water is not given; the time was exactly measured, as well as the quantity of water discharged, and the result was, that the quantity of water discharged in equal times by the same orifices, from the same head of water, is very nearly as the areas of the orifices; and, that the quantities of water discharged in equal times by the same orifices, under different heads of water, are nearly as the square roots of the corresponding heights of the water in the reservoir above the centre of the orifices. If we call Q, q, the quantities of water discharged in the same time from the two orifices A, A′, under the same height of water in the reservoir; q and Q', the quantities of water discharged during the same time by the same aperture A, under the different heads of water h, h'; we have by the first of the above results,

$$Q : q = A : A', \text{ and by the second } q : Q = \sqrt{h} : \sqrt{h'};$$

$$\text{from which we obtain } q = \frac{A' \times Q}{A}, \text{ and } q = \frac{Q' \sqrt{h}}{\sqrt{h'}};$$

$$\text{then, since } \frac{A' \times Q}{A} = \frac{Q' \sqrt{h}}{\sqrt{h'}}, \text{ we have } Q : Q' = A \sqrt{h} : A' \sqrt{h}.$$

The quantities of water discharged during the same time by different apertures, under different heights of water in the reservoir, are to one another in the compound ratio of the areas of the apertures, and of the square roots of the heights in the reservoirs.

M. Michelotti made on this subject a series of experiments on a great scale, and with the utmost accuracy. The apertures extended to 3 inches both square and circular, and at considerable altitudes: the reservoir was 20 feet high, and 3 feet square; the water flowed from it into a cistern whose area was 289 square feet, and the results corresponded nearly with the experiments by Du Buat on the quantity of water discharged over weirs: the depth may be considered as the upper edge of a plank placed below the upper surface of the water in the river or reservoir: one of the orifices was 18½ inches English in length.

Depth of the Orifice in English feet.	Discharge of Water in cubic feet.	Discharge calculated by the Formula.
1·778	506	524
3·199	1222	1218
4·665	2153	2155
6·753	3750	3772

Du Buat has given the following formula reduced to English inches, by which the third column is calculated, and is very accurate. This formula, as altered by Dr. Robinson, is

$$D = l \sqrt{130{\cdot}032\ H^3}, \text{ or}$$

$$D = 11{\cdot}4172\ l H^{\frac{3}{2}};$$

where D is the quantity of water discharged in cubic feet, l the length of the waste-board, and H its depth; that is, multiply the square root of the cube of the depth of the upper edge of the waste board below the surface by 11¼, and by the length of the waste-board, and the product will be the quantity discharged in English inches.

Dr. Robison found by his experiments that the discharge was one-sixteenth more than that produced by Du Buat's formula.

For the Quantity of Water discharged over a Weir, we cannot do better than select a table, drawn up and revised by Dr. Robison, from experiments made in Scotland, which showed some slight variations from the formula given by Du Buat. The water from which the discharge was made was perfectly quiet, but when it was suffered to reach the opening over which it passed with any velocity, it was necessary that the area of the section should be multiplied by the velocity of the stream.

Since the publication of "Traité théorique et experimental d'Hydronamique" by the Abbé Bossut in 1771, this subject has been justly regarded as important, and has received the attention of the most eminent philosophers. Bossut's experiments were made upon a grand scale, and his formulæ are more to be relied on than those given by Michelotti; and in order to determine the motion of the particles of a fluid which was in the act of being discharged from an orifice, Bossut employed a glass cylinder, 8 inches in height and 6 inches in diameter, to the bottom of which he adapted several contrivances for the efflux of the water.

Chevalier Buat, Colonel of Engineers, in 1779, adopted the theory of Bossut, and paid particular attention to the motion of water in rivers and canals, and to him we are indebted for the observation, that if water possessed perfect fluidity, and flowed in a channel infinitely smooth, its motion would be constantly accelerated, like that of heavy bodies descending upon an inclined plane. But the velocity of a river is not accelerated *ad*

infinitum, but soon arrives at a state of uniformity, which is not afterwards increased; new degrees of velocity are not obtained in consequence of being retarded by the friction of its channel.

Depth of the upper edge of the waste-board below the surface in English inches.	Cubic feet of water discharged in a minute by every inch of the waste-board, according to Du Buat's formula.	Cubic feet of water discharged in a minute by every inch of the waste-board, according to experiment made in Scotland.
1	0·403	0·428
2	1·140	1·211
3	2·095	2·226
4	3·225	3·427
5	4·507	4·789
6	5·925	6·295
7	7·466	7·933
8	9·122	9·692
9	10·884	11·564
10	12·748	13·535
11	14·707	15·632
12	16·758	17·805
13	18·895	20·076
14	21·117	22·437
15	23·419	24·883
16	25·800	27·413
17	28·258	30·024
18	30·786	32·710

When the quantity of water discharged over a weir is known, the depth of the edge of the wasteboard, or H, may be found from the following formula, —

$$H = \left(\frac{D}{11{\cdot}4172\,l}\right)^{\frac{2}{3}}$$

Michelotti's experiments give $0{\cdot}2703\sqrt{H}$ for the number of cubical inches discharged in a second over a weir, when the height H is one inch; and the real discharge to the theoretical discharge is 9536 to 1000. These numbers suppose the length of the weir to be infinite; his formula includes only the contractions produced by the upper edge of the waste-board.

M. Eytelwein, in calculating the discharge of rectangular orifices reaching to the surface represents the velocity, which varies as the square root of the height, by the ordinates and the quantity of water discharged by the area of a parabola, two-thirds that of the circumscribing rectangle. This may also be found by taking two-thirds of the velocity due to the mean height, and allowing for the contraction of the vein. He purposes, for example, a lake, in which there is a rectangular opening without any oblique lateral walls, 3 feet wide, and extending 2 feet below the surface of the water: here the co-efficient of the velocity corrected for contraction is 5·1, and the corrected mean velocity $\frac{2}{3}\sqrt{2 \times 5{\cdot}1} = 4{\cdot}8$; therefore, the area being 6, the discharge of water in a second is 28·8 cubic feet: C being the co-efficient corrected for contraction, W the width of the aperture, and H its depth below the surface, we have the general formula,

$$Q = \tfrac{2}{3}\sqrt{H} \times C \times H \times W,$$

for the quantity of water in cubic feet.

As the same co-efficient serves to determine the discharge over a weir of considerable breadth, it is easy to deduce the depth or breadth requisite for the discharge of a given quantity of water: for example, a lake has a weir 8 feet in breadth, and the surface of the water stands at a height of 5 feet above it; it is required how much the weir must be widened that the water may be a foot lower; we have the velocity $= \frac{2}{3}\sqrt{5 \times 5{\cdot}1}$, and the quantity of water $\frac{2}{3}\sqrt{5 \times 5{\cdot}1 \times 3 \times 5}$, but the velocity must be reduced to $\frac{2}{3}\sqrt{4 \times 5{\cdot}1}$, and then the section will be

$$\frac{\frac{2}{3}\sqrt{5 \times 5{\cdot}1 \times 3 \times 5}}{\frac{2}{3}\sqrt{4 \times 5{\cdot}1}} = \frac{\sqrt{5 \times 3 \times 5}}{\sqrt{4}} = 7{\cdot}5 \times \sqrt{5},$$

and the height being 4 feet, the breadth must be $\frac{7{\cdot}5}{4}\sqrt{5} = 4{\cdot}19$ feet.

On the Motion of Water in Rivers. — The theorem by which the velocity of a river is determined, is one of the most valuable of M. Eytelwein's calculations: the friction is nearly as the square of the velocity, not because a number of particles proportionate to the velocity are torn asunder in a time proportionately short, (for according to the analogy of solid bodies no more force is destroyed by friction when the motion is rapid than when

slow,) but because, when a body is moving in lines of a given curvature, the deflecting forces are as the squares of the velocities, and the particles of water in contact with the sides and bottom must be deflected in consequence of the minute irregularities of the surfaces on which they slide, nearly into the same curvilinear path, whatever their velocity may be. The principal part of the friction is as the square of the velocity, and the friction is nearly the same at all depths; it varies, however, according to the surface of the fluid in contact with the solid, in proportion to the whole quantity of the fluid, viz. the friction for any given quantity of water will be as the surface of the bottom and sides of a river directly, and as the whole quantity of water in the river inversely; or, suppose the whole quantity of water to be spread on a horizontal surface equal to the bottom and sides, the friction is inversely as the height at which the river would then stand, which is called the hydraulic mean depth.

When the river flows uniformly, and is neither accelerated nor retarded by the action of gravitation, the whole weight of the water is employed in overcoming this friction, and if the inclination vary, the relative weight, or the force which urges the particles along the inclined plane, will vary as the height of the plane when the length is given, or as the fall in a given distance: consequently the friction, equal to the relative weight, must vary as the fall, and the velocity, which is as the square root of the friction, must be as the square root of the fall; and supposing the hydraulic mean depth to be increased or diminished, the inclination remaining the same, the friction would be diminished or increased in the same ratio; therefore, in order to preserve its equality with the relative weight, it must be proportionally increased or diminished, by increasing the square of the velocity, in the ratio of the hydraulic mean depth, or the velocity in the ratio of the square root. The velocities will, therefore, be conjointly as the square root of the hydraulic mean depth, and of the fall in a given distance, or as a mean proportional between these two lines.

Taking two English miles for a length, we must find the mean proportional between the hydraulic mean depth and the fall in two miles, and inquire what relation this bears to the velocity in a particular case, and thence we may determine it in any other: according to Eytelwein's formula, this mean proportional is $\frac{49}{11}$ of the velocity in a second.

Mr. Watt found that in a canal 18 feet wide above, 7 feet below, and 4 feet deep, having a fall of 4 inches in a mile, the velocity was 17 inches in a second at the surface, 14 inches in the middle, and 10 inches at the bottom, the mean velocity being 14 inches in a second or thereabouts; therefore, to find the hydraulic mean depth, we must divide the area of the section $2\,(18+7)=50$, by the breadth of the bottom and length of the sloping sides added together, whence we have $\frac{50 \text{ feet}}{20{\cdot}6}$, or 29·13 inches; and the fall in two miles being 8 inches, we have $\sqrt{8 \times 29{\cdot}13} = 15{\cdot}26$, for the mean proportional, of which, $\frac{49}{11}$, is 13·9, agreeing exactly with Mr. Watt's observation.

The Po falls 1 foot in two miles, where its mean depth is 29 feet, and its velocity is about 55 inches in a second; our rule gives 58, which is a sufficient approximation to show its accuracy.

To find the velocity of a river from its fall, or the fall from its velocity, we have only to recollect that the velocity in a second is $\frac{49}{11}$ of a mean proportional between the hydraulic mean depth and the fall in two English miles.

For the Slope of the Banks of a River or Canal, Eytelwein recommends that the breadth at the bottom should be two-thirds of the depth, and at the surface ten thirds; the banks will then in general retain their form; the slope of the bank within the water making an angle of 37 degrees with the horizon, or of 4 to 3. The area of such a section is twice the square of the depth, and the hydraulic mean depth two-thirds the actual depth.

The superficial velocity of a river is nearly a mean proportional between the hydraulic mean depth and the fall in two miles, and the mean velocity of the whole water is still more, or nearly nine-tenths of this mean proportional.

The Ganges at 500 miles from the sea has its channel 30 feet deep when the river is at the lowest, and it continues at least this depth to the sea: a section of the ground was taken parallel to one of its branches, in length 60 miles, where the windings of the river were so great as to reduce the declivity on which the water ran to less than 4 inches per mile, its medium rate of motion being less than three miles an hour in the dry months. Allowing a little for the banks, we may take 30 feet as the hydraulic mean depth; then if the fall in two miles were precisely two-thirds, we should have $\frac{2}{3} \times 30 = 20$, and $\sqrt{20} = 4{\cdot}47$ for the velocity of a second, or 3·05 miles in the hour.

This river when full has thrice the volume of water, and its motion is accelerated in the proportion of 5 to 3; the hydraulic mean depth is then doubled, whence the velocity is increased in the ratio of 7 to 5: the inclination of the surface is somewhat increased, which increases the velocity from 1·4 to 1·7.

Smeaton's Experiments relative to undershot Water-wheels. — A B C D is the cistern for supplying the water, D E the upper cistern or head, F G a small rod divided into inches, and moving up and down as the water rises and falls; H I is a rod by which the sluice is drawn, and stopped at any height required by the pin K, which is placed as a diagonal scale upon

the rod H I; G L is the upper part of the rod of the pump for drawing the water out of the lower cistern to the head D E; M M the handle for working the pump, which is limited in its stroke by N; O is the cylinder upon which a cord winds, and passing over the pulleys P and Q raises R, the scale into which the weights are put for trying the power of the waters; S, T, the two standards which support the wheel, and made to slide up and down to adjust the wheel to the floor of the conduit; W is the beam to support the scale and pulleys; X X (fig. 1734.) is the pump-barrel, 5 inches in diameter and 11 inches long; Y is the piston, and Z the fixed valve; G V is a wooden cylinder fixed upon the pump rod, reaching above the surface of the water; its section is half the area of that of the pump barrel, which causes the surface of the water to rise in the head as much while the piston is descending as while it is rising, and keeps the gauge rod more equally to its height; *a a* is one of the two wires which serve as directors to the float, so that the gauge rod F G may be kept perpendicular; *b* is the aperture of the sluice; *c c* is a kant board for throwing the water down the opening, *c d*, into the lower cistern; *e e* is a sloping board for bringing the water back that is thrown up by the floats of the wheel.

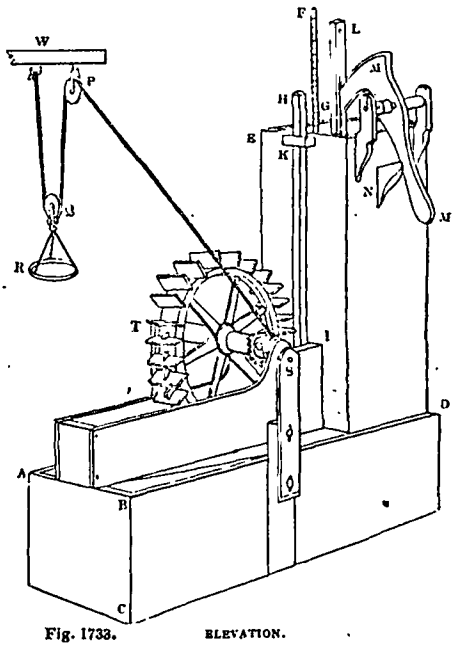


Fig. 1733. ELEVATION.

Fig. 1733. represents one end of the main axis, with a section of the cylinder marked O. A B C D is the end of the axis; B, D are covered with hoops of brass; E is a metal cylinder; F the gudgeon; *a a* is the section of a brass ferrule, *c c*. The section of the hollow cylinder of wood, *e e*, is cut into teeth, and *o o* a ratchet; G is a pin fixed into the axis, by means of which the hollow cylinder turns along with the wheel and axle; when drawn back by the button *g g*, the hollow cylinder is disengaged from the pin G, and ceases turning; the weight on the scale is prevented running back by a catch that lays hold of the ratchets *o, o*; the hollow cylinder is by this contrivance put in motion and discharged while the wheel is in motion.

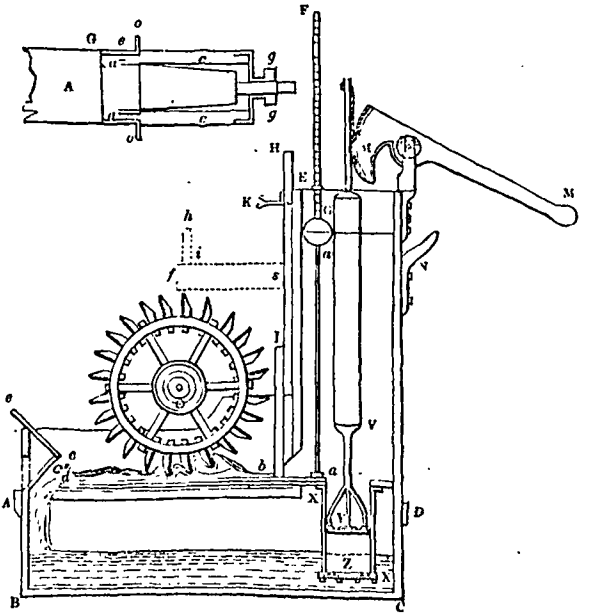


Fig 1734. SECTION OF MACHINE.

The Power is the exertion of strength,

gravitation, impulse, or pressure, which produces motion. Raising a weight to a given height in a given time is the measure of power; the weight raised, multiplied by the height, gives a product which is the measure of the power that raised it: when velocity is uniform, the space is as the velocity; then the power is proportionate either to the force multiplied by the velocity, or the space described; it is unimportant whether the motion be quick or slow if it be uniform. The original power is somewhat lessened by the friction of the machinery and the resistance of the air, which, before the useful effect can be obtained, must be calculated: from the velocity of the water at the instant it strikes the wheel, the height of head productive of such velocity can be deduced; then, multiplying the weight of water expended in any period of time by the height of the head, we have the power of the water; the sum of the weight raised by the action of the water, and that required to overcome the friction and resistance, multiplied by the height to which the weight can be raised in a given time, the product will be the effect of the power: the proportion of the two products is that of the proportion of the power to the effect.

To determine the Velocity of the Water striking the Wheel, according to Smeaton. — When the wheel of a machine is put in motion by the water without any weight in the scale, supposing the number of turns in a minute to be 60, then 60 times the circumference of the wheel will be the space through which the water would have moved in a minute if the wheel were free from friction and resistance; the velocity is, however, greater than this, as considerable deduction must be made for friction: suppose the cord wound round the cylinder in a contrary direction to the usual method, and a weight put into the scale; this weight will assist the wheel in turning; suppose it to be sufficient to cause the machine to turn without any water somewhat faster than 60 turns a minute, as 63; let the water then be applied, assisted by the weight, the wheel will now make 64 turns; hence we may suppose that the water exerts some power in giving motion to the wheel; increase the weight, so as to make 64½ turns in a minute without water, and then try it with water as before. and if it make the same number of turns with water as without, it must be evident that the wheel makes the same number of turns in a minute as it would do if the wheel had no friction, the weight being equivalent thereto; if this were too little, the water would accelerate the wheel beyond the weight, and if too great, retard it; thus the water becomes the regulator of the wheel motion of the wheel, and the velocity of its circumference becomes a measure of the velocity of the water.

To find the greatest product, or *maximum of effect*, the weight which gives the greatest product being known, multiply the weight in the scale by the number of turns of the wheel; find what weight in the scale, when the cord is on the contrary side of the cylinder, will cause the wheel to make the same number of turns in one direction without water. It is evident that the weight will be equal to all the friction and resistance taken together, and consequently the weight of the scale added to the counterweight will be equal to the weight that could have been raised if the machine had been without friction or resistance, which, multiplied by the height to which it actually was raised, the product will be the greatest effect of that power. This method, however, does not give the actual resistance when the maximum power and load are upon the wheel, but only the friction from the weight of the apparatus, when moving at a velocity corresponding to the maximum. The effect was estimated by Smeaton at considerably less than its true value.

Quantity of Water expended, or its Dynamic Effect on Wheels. — The pump was so well made, that it delivered the same quantity of water at each stroke, whether worked slowly or quick, the length of the stroke being limited. The sluice by which the water was drawn upon the wheel was stopped at a certain height by a peg; the aperture for the effluent water was the same, so that the exact quantity of water expended was known; the sluice being drawn to the first hole.

	Inches.
The water above the floor of the sluice	30
Strokes of the pump in a minute	39¼
The head raised by twelve strokes	21

	Turns in a Minute.
The wheel raised the empty scale, and made	80
With a counterweight 11 lbs. 8 oz.	85
Ditto, tried with water	86

No.	Lbs	oz.	Turns in a Min.	Product.
1	4	0	45	180
2	5	0	42	210
3	6	0	36½	217½
4	7	0	33¾	236¼
5	8	0	30	240; maximum.
6	9	0	26½	238½
7	10	0	22	220
8	11	0	16½	181½
9	12	0	ceased working.	

Counterweight for 30 turns, without water, 2 oz. in the scale; the area of the head was 105·8 square inches; weight of the empty scale and pulley 10 oz.; circumference of the cylinder 9 inches; circumference of the water-wheel 75 inches.

The circumference of the wheel 75 inches, multiplied by 86 turns, gives 6450 inches for the velocity of the water in a minute, $\frac{1}{60}$ of which will be the velocity per second, equal to 107·5 inches, or 8·96 feet, the head being 15 inches, and the vertical or effective head, which differs from the real head by the velocity lost by the fluid in issuing through the aperture of the sluice, and the friction of the channel. The area of the head being 105·8 inches, this multiplied by ·579, the weight in avoirdupois ounces of a cubic inch of water, gives 61·26 ounces for the weight of as much water as is contained in the head upon 1 inch in depth, $\frac{1}{16}$ of which is 3·83 lbs.; this multiplied by the depth, 21 inches, gives 80·43 lbs. or the value of twelve strokes; and by proportion, 39½, the number made in a minute will give 264·7 lbs. as the weight of water expended in a minute: 264·7 lbs. of water, having then ascended through a space of 15 inches in a minute, the product of these two numbers, 3970, will express the power of the water to produce mechanical effects, which upon this wheel were as follows:—

The velocity of the wheel at the maximum was thirty turns in a minute; this multiplied by 9 inches, the circumference of the cylinder, makes 270 inches; but as the scale was hung by pulley and double line, the weight was only raised 135 inches.

	lbs.	oz.
The weight in the scale at the maximum - - -	8	0
Weight of the scale and pulley - - - -	0	10
Counterweight of the scale and pulley - - -	0	12
Sum of the resistances - - - - -	9	6

or 9·375 lbs.

Now, as 9·375 lbs. are raised 135 inches, these two numbers multiplied together produce 1266, the effect produced as a maximum; so that the proportion of the power to the effect is as 3970 : 1266, or as 10 : 3·18. Though this is the greatest single effect by the impulse of the water upon an undershot wheel, yet, as the whole power of the water is not exhausted thereby, this will not be the true ratio between the power of the water and the sum of all the effects producible therefrom; for as the water must necessarily leave the wheel with a velocity equal to its circumference, it is clear that some part of the power of the water must remain after quitting the wheel. The velocity of the wheel at the maximum is 30 turns in a minute, so that its circumference moves at the rate of ·3·123 feet per second, which answers to a head of 1·82 inches; this being multiplied by the expenditure of water in a minute, viz. 264·7 lbs., produces 481 for the power remaining in the water after it has passed the wheel; this being, therefore, deducted from the original power, 3970, leaves 3489, which is that portion of the power spent in producing the effect 1266, which is to the greatest effect producible thereby, as

3489 : 1266 :: 10 : 3·62, or as 11 to 4.

The velocity of the water striking the wheel has been determined as equal to 86 circumferences of the wheel per minute, and the velocity of the wheel at the maximum to be 30; the velocity of the water will, therefore, be to that of the wheel, as 86 to 30, or as 10 to 3 5, or 20 to 7: the load of the maximum was equal to 9 lbs. 6 oz.; and the wheel ceased moving with 12 lbs. in the scale, to which the weight of the scale was added, viz. 10 ounces; the proportion, therefore, will be nearly as 3 to 4 between the load of the maximum, and that by which the wheel is stopped. The velocity of the wheel in relation to the water is proved to be greater than ⅓ the velocity of the water; yet the impulse of the water, in the case of a maximum, is more than double that assigned by theory, viz. instead of ⅔ of the column, it is nearly equal to the whole column: the power of the water is equal to the velocity and pressure due to the effective head. The resistance reduced to the circumference of the wheel is equal to the weight raised, added to the friction of the machine when raising that weight, multiplied by the velocity of the wheel. The maximum of useful effect takes place when the greatest weight is raised with the greatest velocity: in the case experimented upon, to prove this, the wheel was not placed in an open river, where the natural current, after it has communicated its impulse to the float, has room on all sides to escape, as the theory supposes.

After numerous experiments, Smeaton ascertained that the vertical or effective head being the same, the effect will be nearly as the quantity of water expended; and that the expense of water being the same, the effect will be nearly as the height of the vertical or effective head, and the effect nearly as the square of its velocity: the aperture being the same, the effect will be nearly as the cube of the velocity of the water.

Bossut's experiments on undershot water-wheels confirm many of Smeaton's results: he tried their effect in a close canal, as well as in an open stream, varying in both cases the

number of floats. In the close canal, he made use of a wheel the extreme diameter of which was 3 feet 1·87 inches, 5 inches in breadth, and the depths of the float-boards from 4 to 5 inches: the axis of the wheel which received the cord was 2 inches in diameter; the diameter of the pulley $3\frac{3}{4}$ inches. The wheel was suspended on its axis within half a line of the bottom of the canal: the sluice was raised 1 inch, and the velocity of the stream was 300 feet in 33 seconds: in a close canal, the effect was with 48 floats on a wheel of 3 feet 1·87 inches diameter greater than that with a less number: the arc immersed was about $\frac{1}{16}$ of the circumference of the wheel.

Water-wheels used in rivers have a less number of float-boards, and in the next experiment the wheel was 3 feet diameter, breadth 6 inches, and the depth of the float-boards 6 inches, the whole weight of the moving parts of the apparatus being 44 lbs.

The stream was open, 12 or 13 feet wide, and 7 or 8 inches deep, and the float-boards were immersed 4 inches: the wheels had a variety of float-boards, that with 48 producing very little more effect than one with half that number; but there was considerable difference between those with 24 and 12, the former being decidedly preferable: it was apparent, when the wheel dipped $\frac{1}{8}$ of its circumference, less than 24 ought not to be used.

In the close canal the sluice was raised 2 inches, the velocity of the current 300 feet in 27 seconds, and 48 float-boards to the wheel; and trials were made with the same wheels, the maximum effect of which was $34\frac{1}{2}$ lbs., raised by $20\frac{3}{10}$ turns of the wheel in 40 seconds, thus making the product of the weight raised $704\frac{1}{2}$ lbs. The velocity of the current was to the velocity of the outer circumference of the wheel, as 10 is to 4·32 when the power is a maximum.

In the open stream, where the velocity of the current was $68\frac{1}{2}$ inches per second, the float-boards dipping 4 inches in the water, the wheel having 24 float-boards, the maximum effect was 60 lbs. weight raised, $11\frac{5}{8}$ being the number of turns of the wheel in 40 seconds, and 710 the product of the weight by the number of turns. The velocity of the current was to the velocity of the outer edge of the float-boards at the maximum, as 10 is to 4·9 nearly. The velocity of the wheel in the stream and in the canal was nearly the same. The greatest effect, as it appears from Bossut's trials, was obtained when the inclination of the floats to the radius was from 15 to 30 degrees.

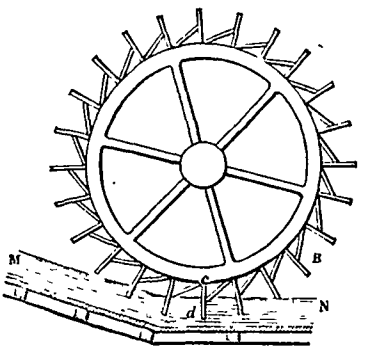


Fig. 1735. UNDERSHOT WHEEL.

Construction of Undershot Wheels.—The wheel here represented has twenty-four float-boards; *c d* is that receiving the impulse of the water, which, in consequence of falling from a height, moves with great velocity down the inclined mill-course M N, the construction of which requires the greatest consideration, as does the number, form, and position of the float-boards, and the velocity of the wheel, in relation to that of the water, when the effect is a maximum: it being important to have the height of the fall as great as possible, the canal or dam which conducts the water from the head should not have more inclination than is absolutely necessary; an inch in 200 yards is considered sufficient, care being taken to make the declivity for the first 50 yards about $\frac{1}{2}$ inch, that the water may have sufficient velocity to prevent its running back into the head.

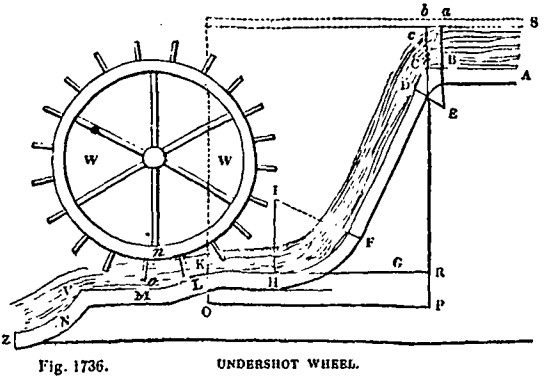


Fig. 1736. UNDERSHOT WHEEL.

The inclination of the fall, shown by the angle C G R, should be 25° 50′, or C R; the radius should be to C R, the tangent of the angle, as 25 to 12; and since the surface of the water S*b* is bent from *ab* into *ac* before it is precipitated down the fall, it will be necessary to

incurvate the upper part B C D of the course into B D, that the water at the bottom may move parallel to that at the top of the stream. To effect this, take the points B, D, about a foot distant from C, and raise the perpendiculars B E, D E; the point of intersection E will be the centre from which the arc B D is to be described, the radius being about 10⅛ inches. That the water may act more advantageously upon the float-boards of the wheel W W, it must assume a horizontal direction H K, with the same velocity that it would acquire when it came to the point G; but in falling from C to G, the water will dash upon the horizontal part H G, and thus lose a great portion of its velocity; it will be necessary, therefore, to make it move along F H, an arc of a circle to which D F and K H are tangents, in the points F and H. For this purpose make G F and G H each equal to 3 feet, and raise the perpendiculars F I, H I, which will intersect each other at the point I, distant about 4 feet 9$\frac{4}{10}$ inches from the points F and H, and the centre of the arc F H will be determined. The distance H K, through which the water runs, before it acts upon the wheel, should not be less than 2 or 3 feet, in order that the different portions of the fluid may obtain a horizontal direction, and if H K be much larger, the velocity of the stream would be diminished by its friction on the bottom of the course. That no water may escape between the bottom of the course K H, and the extremities of the float-boards, K L should be about 3 inches, and the extremity O of the float-board, N O, should be beneath the line H K K, sufficient room being left between O and M for the play of the wheel, or K L M may be formed into the arc of a circle, K M, concentric with the wheel.

The line L M V, or the course of compulsion, should be prolonged, so as to support the water as long as it can act upon the float-boards, and about 9 inches distant from O P, a horizontal line passing through O, the lowest point of the fall; for if O L were much less than 9 inches, the water, having spent the greater part of its force in impelling the float-boards, would accumulate below the wheel and retard its action: for the same reason the course of discharge should be connected with L M V by the curve V N, to preserve the remaining velocity of the water, which would otherwise be destroyed by falling perpendicularly from V to N. The course of discharge is represented by V Z, sloping from the point O; it should be about 16 yards long, having an inch of declivity in every 2 yards.

The canal which conducts the water from the course of discharge to the river should slope about 4 inches in the first 200 yards, 3 inches in the second 200 yards, decreasing gradually till it terminates with the river. The diameters of undershot wheels must be in accordance with the machinery on which they are to act; when a great velocity is required, the wheel must be of a less diameter than is usually recommended; when this is not required, the diameter of the wheel should be as large as possible.

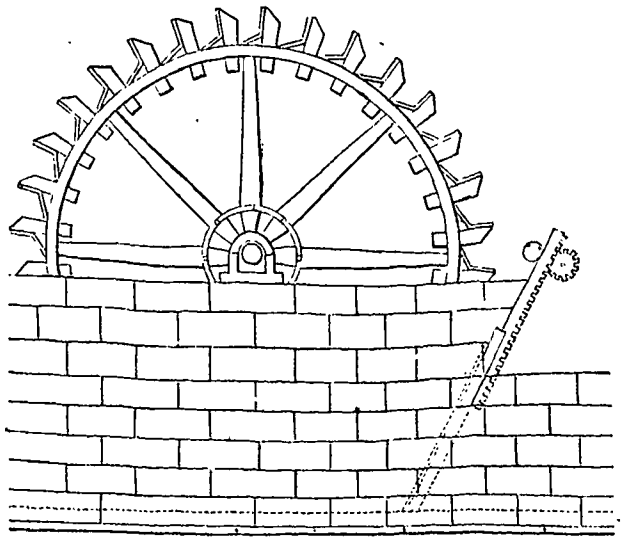


Fig. 1737. SIDE ELEVATION OF AN UNDERSHOT WHEEL.

The number of float-boards, according to Pitot, should be equal to 360°, divided by the arc of the circle plunged in the canal, and their depth equal to the versed sine of that arc; but this number experience has proved to be too small, and some engineers have

maintained that it is not possible to have too many float-boards, provided the wheel is not too much loaded with them.

It may be readily understood, that when water acts by its momentum only, the circumference of the wheel, instead of requiring buckets, as in the overshot wheel, is furnished with float-boards, which, exposed to the action of running water, may have its power increased by a well regulated fall; such a wheel may communicate its force to any machinery. The figures show the method that Smeaton recommended for the construction of undershot wheels; the sluice or *penstock* is raised or depressed by a ratchet and pinion; the spur-wheel to drive the machinery is shown resting on its bearings on the left of the elevation.

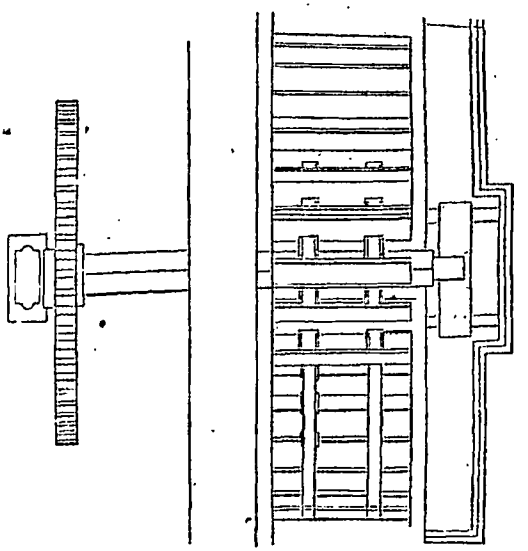


Fig 1738. PLAN OF UNDERSHOT WHEEL.

On Overshot Wheels, by Smeaton. — We now proceed to examine the power and application of water, when acting by its weight: we might at first be led to suppose, that the same quantity of water descending through the same perpendicular space would produce equal power, when the machinery is freed from friction, and that if the height of a column of water be 30 inches, and its base or aperture 1 inch, every cubic inch that passes through the aperture would acquire the same momentum, a column of uniform pressure being always maintained, as one cubic inch let fall from the top will acquire in falling down to the level of the aperture; but that this is not exactly the case, experiment has proved.

The alterations made in the machinery we have already described were as follows: the sluice I *b* (fig. 1733.) being shut down, the rod H I was unscrewed and taken off. The undershot wheel was removed, and an overshot put in its place, of 2 inches in the depth of the bucket, and the number of buckets was thirty-six: the standards S and T were raised half an inch, so that the bottom of the wheel might be clear of dead water; a trunk for bringing the water to the wheel was fixed according to the dotted lines *f, s*. The ratchet *o o* not being of one piece of metal with the ferrule was with its catch turned to the contrary side: the movable barrel acted by this means, although the water-wheel moved the contrary way; the results were, head 6 inches; 14½ strokes of the pump in a minute, 12 do. = 80 lbs.; weight of the scale being wet, 10½ oz.; counterweight for twenty turns, besides the scale, 3 oz. In the maximum experiment there were 20¾ turns in a minute, each of which raised the weight 4½ inches, or 93·37 inches in a minute; the weight in the scale was 19 pounds; the weight of the scale 10¼ ounces; the counterweight three ounces in the scale, making with the weight of the scale 20¼ pounds, and which was the whole resistance or load; this multiplied by 93·37 inches, gives 1914 for the effect.

The ratio of the power and effect is 2900 : 1914, or 10 : 6·6, or as 3 to 2 nearly. If we, however, compute the power from the height of the wheel only, we shall have 96¾ lbs. multiplied by 24 inches, equal to 2320 for the power, and this will be to the effect as 2320 : 1914, or as 10 : 8·2, or as 5 to 4 nearly.

On the most proper Height of the Wheel in proportion to the whole Descent. — We have already observed that the effect of the same quantity of water descending through the same perpendicular space is double, when acting by its gravity on an overshot wheel, to that produced by the same when acting by its impulse upon an undershot: it also appears, that by increasing the head from 3 inches to 11, that is, the whole descent from 27 to 35 inches, or in the ratio of 7 to 9 nearly, the effect is only in the ratio 8·1 to 8·4, that is as 7 to 7·26; consequently, the increase of effect is not a seventh of the increase of perpendicular height; hence, the higher the wheel is in proportion to the descent, the greater will be the effect, as it depends less upon the impulse of the head, and more upon the gravity of the water in the buckets.

The Velocity of the Circumference of the Wheel which produces the greatest Effect. — If a body be allowed to fall freely from the surface of the head to the bottom of the descent, it will take a certain time in falling, and in that case the whole action of gravity is spent in

giving the body a certain velocity, but if in falling, it be made to act upon some other, so as to produce a mechanical effect, the falling body will be retarded, because a portion of the action of gravity is then spent in producing that effect, and the remainder only will give motion to the falling body; therefore the slower a body descends, the greater will be the portion of the action of gravity applicable to producing a mechanical effect, consequently the greater that effect will be. A stream of water falling into the bucket of an overshot wheel is there retained until the rotary motion of the wheel discharges it; the slower the wheel moves the more water each bucket receives, so that what is lost in speed is gained by the pressure of a greater quantity of water acting on the buckets at once; thus the mechanical power of an overshot wheel produces equal effects, whether it move quickly or slowly: when the wheel, according to the experiments, made 20 turns in a minute, the effect was nearly the greatest; when 30 turns the effect was diminished one-twentieth; when 40 turns it was diminished one quarter; when less than 18¼ its motion was irregular, and when loaded so as not to admit of its making 18 turns, it was overpowered. The velocity most available in practice is that produced by a wheel making 30 turns in a minute, and the velocity of the circumference is a little more than 3 feet in a second. Experience also proves that the velocity is applicable to the highest overshot wheels, as well as the lowest.

Smeaton, in the year 1796, put up an overshot wheel at Hull, some years after these experiments were made, the diameter of which was 27 feet, and he directed that it should move at the rate of 8½ feet per second, remarking that its motion would not be equal and regular if it moved at the rate of 3 feet per second.

The load for an overshot wheel that will produce a maximum effect is that which reduces the circumference of the wheel to its proper velocity; and this will be ascertained by dividing the effect it ought to produce in a given time by the space intended to be described by the circumference of the wheel in the same time; the quotient will be the resistance overcome at the circumference, and is equal to the load required, the friction of the machinery included.

The greatest possible velocity of which the circumference of an overshot wheel is capable depends jointly upon the height of the wheel and the velocity of falling bodies.

The greatest load that an overshot wheel can overcome is unlimited.—According to Eytelwein the power which operates upon overshot water-wheels is divided into two parts; one derived from the weight of the water in the buckets, the other from the impulse of the water falling on it: the effect of the first is constant, that of the second varies with the velocity; the maximum is said to be when the velocity is half that of the water received, but the variable portion being the smaller, the rule is of little practical importance, and the velocity of the wheel is generally greater than this; by turning the stream back upon the nearer half of the wheel, we remove the resistance of the lower water, which runs off in the same direction as that of the water-wheel. The iron overshot wheels have the same arrangement of the pen-trough and shuttle for the supply of water as the other description of wheels, and can be regulated in a similar manner.

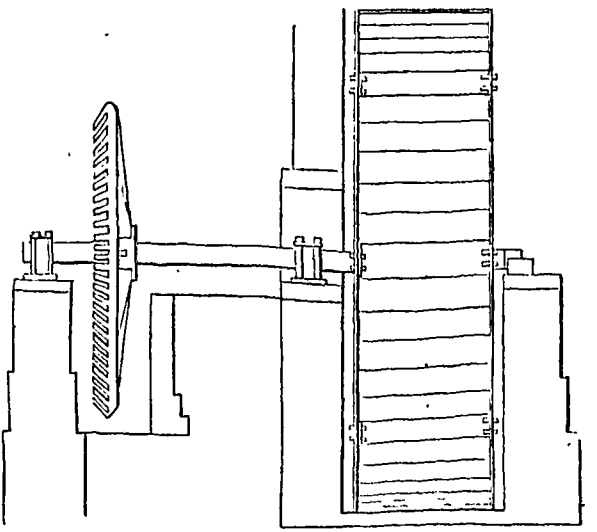


Fig. 1739. OVERSHOT WHEEL.

On the Construction of Overshot Water-wheels.—When the water is permitted to fall into the bucket *c*, (fig. 1740.) from the horizontal mill-course E F, the weight of water in the bucket acting at the end of the levers equal to *m* O puts the wheel in motion in the direction *c d*, and all the buckets, which are filled in succession as the wheel turns round. When the bucket *c* reaches the position *d*, its power to turn the wheel is increased, becoming equal to the

weight of water acting at the end of the lever n O, equal to the distance of its centre of gravity, d, from a vertical line passing through the axis O. Thus the mechanical effect of the water in the bucket increases till it arrives at B, after which in its progress towards C it diminishes. The power of an overshot wheel depends much upon the form of the buckets, which should always be the fullest when at the point B, and should retain the water as long as possible.

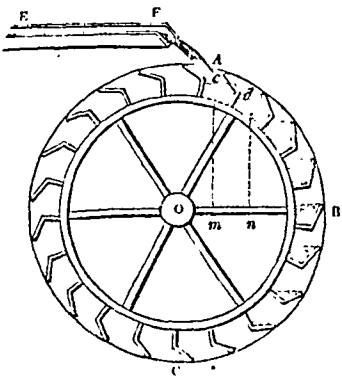


Fig. 1740. OVERSHOT WHEEL.

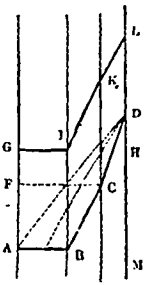


Fig. 1741.

The form of bucket preferred (fig. 1741.) is composed of three partitions; A B and G I, called the start or shoulder, which lies in the direction of the radius of the wheel; B C and I K the arm, inclined at an obtuse angle to the radius; and C D, K L the *wrest*, inclined to an angle less than 180°, to the arm B C or I K; the depth, A G, of each bucket is about 1⅛ of G H; A B is half A M, and the angle A B C is such that B C and G I prolonged would pass through the same point H; it ends, however, in C, so that F C is five-sixths of G H, and C D is so placed that H D is nearly a fifth of H M: hence, it follows that the arc F A B C is nearly equal to D A B C, so that the quantity of water F A B C will continue in the bucket when A D is in a horizontal position, which is the case when A B forms an angle of about 35° with the vertical line.

There are several methods for supplying overshot wheels with water; in some instances it is let on a little below the upper part, or is varied to different heights, in which case the wheel must be adjusted to suit the lowest head, which is a disadvantage.

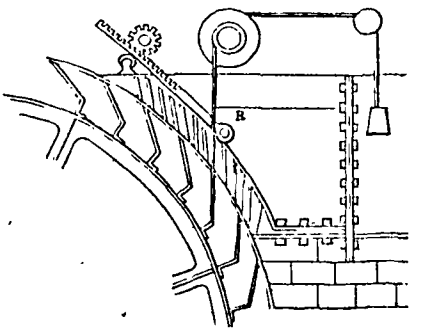


Fig. 1742. PENTROUGH.

The Pentrough is made of cast-iron, and the water runs over the upper side of the roller R, through barred spaces into the buckets of the wheel.

Barker's Mill is supplied by water from a reservoir, and conducted by an upright pipe into the horizontal trunk O, which has arms of an equal length, and through the ends of which the water runs out. The upright spindle is fixed in the bottom of the trunk, to which it is screwed by a nut, in such a manner that when the trunk or upright pipe is turned round, the spindle moves with it; to this spindle the *rynd* of the upper millstone is attached: when water is admitted from the constant reservoir into the cup at the top of the vertical pipe, and suffered to run out by a continued stream from the ends of the trunk, the upper millstone, together with the trunk tube and spindle, turn round.

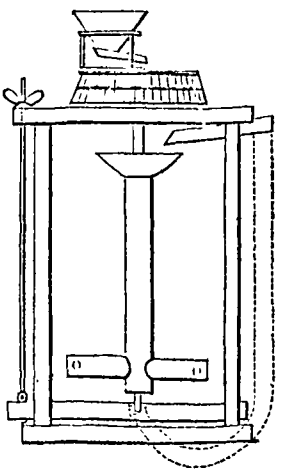


Fig. 1743. BARKER'S MILL.

The length of the axis in a mill of this kind must always exceed the height of the fall, and therefore there is some difficulty in introducing Barker's mill when the fall is very high. M. Mathon de la Cour proposed that the water should be introduced from the mill-stream into the horizontal arms, which are fixed to the upright spindle without having any tube; when the water would issue from the openings below in the same manner as when introduced at the top of the tube as high as the fall. There are

several varieties of Barker's mill; one consists of a number of tubes arranged within the circumference of a truncated cone, so that when the water is introduced into the upper ends of these tubes, and allowed to flow out at the lower, a motion is produced around the axis of the cone. Another contrivance introduces the water from the mill-stream into an annular cavity of a fixed cylindrical vessel, in the bottom of which are several inclined apertures, for the purpose of making the water flow out with a proper obliquity into an inferior vessel, which is movable and of the form of an inverted frustum of a cone; this latter moves about an axis which passes through the centre of the fixed vessel; it has a number of tubes contrived around its circumference, which do not extend to the top, and are bent at the lower ends into right angles. When the water is introduced into the upper vessel, and delivered into the tubes of the lower as it issues from their horizontal extremities, motion is conveyed to the conical drum.

The theory of this engine is not thoroughly understood, and Davies Gilbert, Esq., when President of the Royal Society, decided against any mechanical advantage being produced by it. In the Philosophical Transactions for 1827 are several statements and calculations on the subject.

Hachette has given us in his *Cours de Géometrie Descriptive* the figure of a machine by which the power of lateral pressure may be measured: as the water from the constant reservoir pours into the cup and turns round the spindle, it is made to raise a weight hung over a pulley, which weight at once expresses its power.

Wind is produced by a fall of water, and Venturi has shown that the air is dragged down upon the principle of the lateral communication of motion in fluids; and he has pointed out the best mode of constructing the machine, so as to produce the greatest quantity of air.

According to the author just quoted, rain-water flows out of gutters by a continued current; but during its fall it separates into portions in the vertical direction, and strikes the pavement with distinct blows; the air which exists between the vertical and horizontal separations of the water which falls is impelled and carried downwards; other air succeeds laterally, and a current is produced round the place struck by the water: blasts, or *venturoli*, are also produced by the difference of temperature between the air of a cavern and the external air.

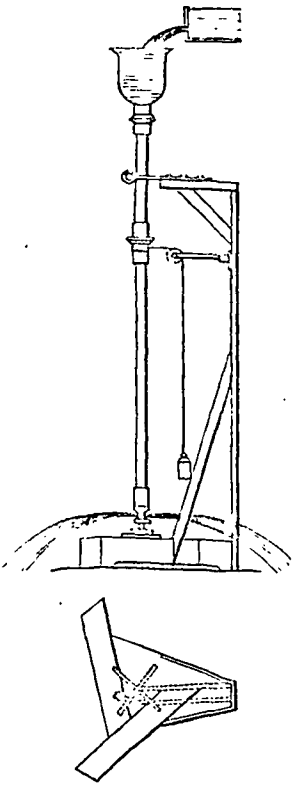


Fig. 1744. LATERAL PRESSURE.

The Tide Wheel is put in motion by the ebbing and flowing of the tide, and in consequence of the variable head of water, the sluices are different to those of other wheels. In the tide mill erected at East Greenwich, on the Thames, the water-wheel has its axle parallel to the side of the river, or to the sluice-gates, through which it enters: the length of the wheel is 26 feet, its diameter 11 feet, and its number of float-boards thirty-two; the latter do not each run on one plane from one end of the wheel to the other, but the whole length of the wheel is divided into four equal portions, and the parts of the float-boards belonging to each fall gradually, one lower than another, each by one-fourth of the distance from one board to the other, as measured on the circumference: by this means all jerking is prevented, and the action of the water on the wheel equalised.

The wheel with its incumbent apparatus weighs 20 tons, the whole of which is raised by the impulse of the flowing tide when admitted through the sluice-gates: it is placed in the middle of the water-way, with a passage on each side 6 feet wide, through which the water flows into the reservoir.

After the tide is mounted to its extreme height, which is 20 feet above low water-mark, the water runs back from the reservoir into the Thames, when a contrary motion is given to the tide wheel: the most ingenious part of the machinery is that by which the wheel is raised and depressed.

Suppose A B to be the section of the water-wheels, and P the vertical shaft, which carries two equal wallower wheels, E, F, so placed that either of them may, as occasion requires, be driven by the first wheel D; and the first wheel acting upon the wallowers F and E at points diametrically opposite, will, although its own motion is reversed, communicate the rotary motion to the vertical shaft always in the same direction. In the figure, the wheel

E is shown in gear, while F is clear of the cog-wheel D, and at the turn of the tide the wheel F is let into gear, and E is thrown out; this is effected by the lever G whose fulcrum is at H, the other end being suspended by the rack K, which holds the pinion on the same

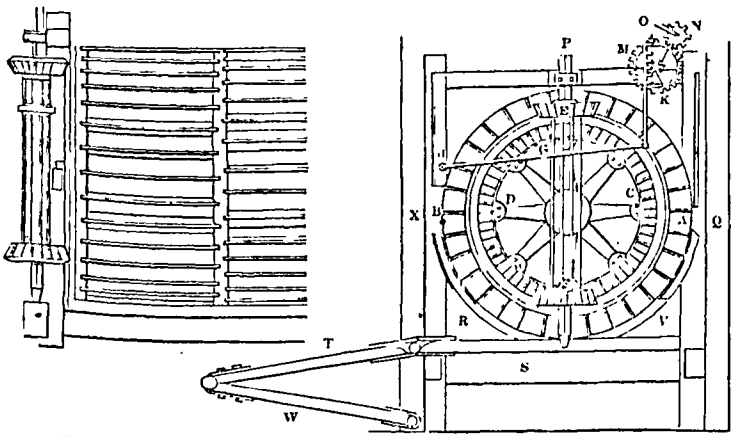


Fig. 1745. SECTION OF WATER-WHEEL.

axle as the wheel M: into this wheel plays the pinion N, and the winch, O, on the other end of the axle, enables the attendant to elevate or depress the wallower wheels as required.

When the tide is flowing, after the mill is stopped a sufficient time to gain a moderate head of water, it is admitted upon the wheel through a sluice at Q, and the tail water runs out at R. The hydrostatic pressure of the head of water acting against the bottom of the wheel frame S, and at the same time between the folding gates T, W, which are thus converted into very large hydrostatic bellows, buoys up the wheel and frame, and mounts them higher and higher, so that the wheel is never *drowned* in the flowing water, which cannot escape under the wheel frame, being prevented by the folding gates, which pass from one end to the other of the wheel. The wheel and frame are thus buoyed up by a head of 4 feet, and the mill works with a head of 5 feet, or a little more.

When the tide is ebbing, and the water is running from the reservoir into the Thames, it might be supposed that the water-wheel would gradually lower with the subsiding of the water; but to prevent this there are strong rack-works, of cast-iron, by which the wheel frame can be either suspended at any height or let gradually down, so as to give the water returning an advantageous head upon the wheel: the sluice R is then shut, and V opened as well as X, the water entering at X, to act upon the wheel, and flowing out at R.

At each end of the water-wheel is a vertical shaft with wallowers, and a first cog-wheel, as F and E, and each of the vertical shafts turns a large horizontal wheel, at a suitable distance above the wallowers, while each horizontal wheel drives four equal pinions placed at equal or quadrantal distances on its circumference, each pinion having a vertical spindle, on the upper part of which the upper millstone of its respective pair is fixed.

The vertical shaft at each end of the water-wheel rises and falls with it, but the large horizontal wheel, which drives the machinery, remains always in the same horizontal plane, and in contact with the four pinions.

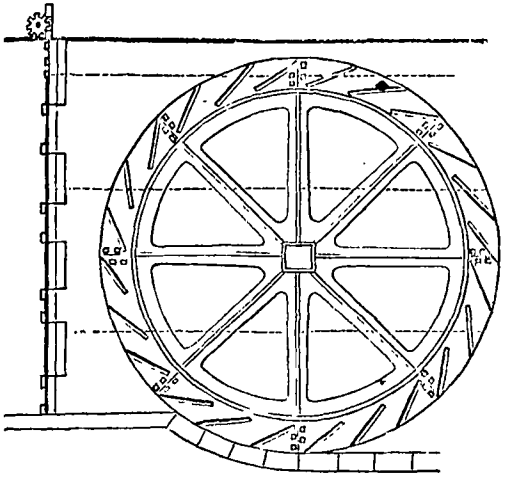


Fig. 1746. DRYDEN'S TIDE-WHEEL.

In the tide-wheel contrived by Mr. Dryden, fig. 1746., the floats are all set at one and the same angle with the respective radii of the wheel, and have an opening of an inch between each float and the drum board or *soling* of the wheel: by this arrangement, the wheel is not impeded by the tail water, and as the bucket rises out of the water, there can be no vacuum formed in it, there being a full supply of air, in consequence of which the wheel is free. Dr. Gregory in his Mechanics has given a clear description of the tide mill, to which we must refer those readers who may be desirous of further information.

The Breast Wheel, now generally made of iron, differs from the undershot in requiring

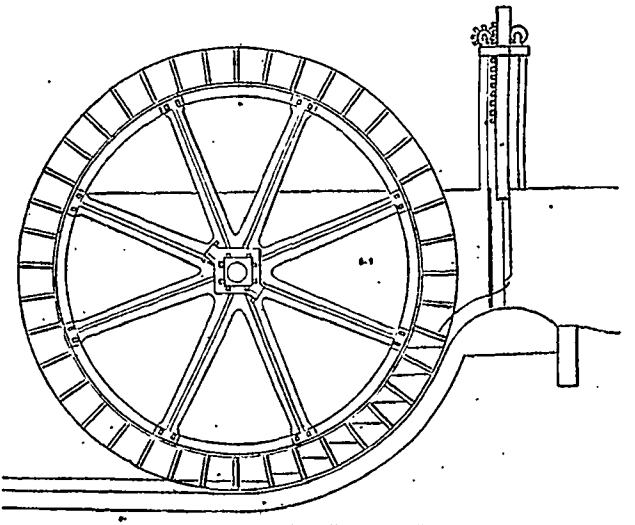


Fig. 1747. ELEVATION OF IRON BREAST-WHEEL.

to be closely boarded, or, as it is called, closely *soled* round its circumference; the sides are also close *shrouded*, or made so as to retain the water, thus forming in effect a bucket-wheel.

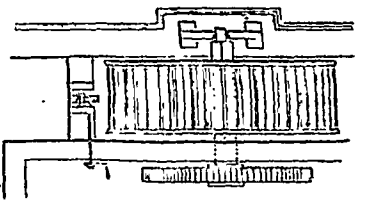


Fig 1748. PLAN OF BREAST-WHEEL.

The Pentrough, for conducting the water, has a rack and pinion, which raises or lowers the *shuttle* that regulates the supply.

Of Bodies plunged in Water. — When a body is placed lightly on the surface of still water, one of three things will happen, —

1st, If the specific gravity of the body be less than that of water, it will swim, and only displace a volume of water equal to its own.

2dly, If the specific gravity be equal to that of water, it will sink totally, and rest between two waters.

3dly, If the specific gravity be greater than that of water, it will descend, and be driven towards the bottom with a force expressed by the excess of its weight over that of the volume of water the place of which it occupies.

To demonstrate the first case, suppose a vessel of a prismatic form A B C D, placed on the surface of water, and that more be gently poured into it to the height E F, which we shall consider as an increase of the column below G A D H, which being heavier than the others of the same base will descend and cause

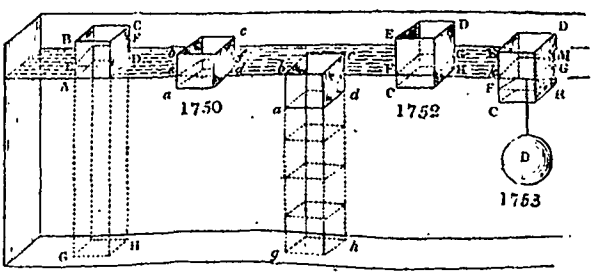


Fig. 1749. Fig. 1751.

them to rise to its level; thus the first *aefd* (fig. 1750.) may be regarded as making a part of the totality of the water: and as the weight of the water contained in the vessel *abcd* was the cause of its sinking, if a body of equal weight be substituted for it, the vessel will sink to the same depth as before, that is, it will occupy the place of a volume of water of a weight equal to that which it will contain. If the vessel *abcd* be a solid body of a weight equal to the water which it can contain, it will sink to the same depth as before, to occupy the place of a column of water in weight equal to its own: hence the specific gravity of the prism *abcd*, considered as a solid, will be to that of the water reciprocally as the height *ae* of the water in which the prism is sunk, is to the height *ab* of the prism itself: when, also, a body lighter than the column it displaces is forced into water, it is driven from below upwards by the surrounding columns, with a force equal to the excess of the weight of this volume over that of the body.

In the second case, if water be continually poured into the vessel *abcd* (fig. 1751.) to fill it, it will continue to sink until the surfaces of the two columns of water are at the same level; the vessel being then entirely plunged in the reservoir will form a part of the column *gbch*, which becoming in equilibrio with the others, the vessel will be so also. If the height *gb* of the column *gbch* contain several times that of the vessel, this column will be composed of several prisms *abcd*, and it being indifferent to the equilibrio whether one be at the surface or bottom of the fluid, at whatever part the vessel be placed, it will be in equilibrio with all that surrounds it. Since the volume which a body occupies in water may be considered as forming a part of the totality of the water itself, it follows, that when a body of a greater or less specific gravity than water is plunged therein, the bottom of the vessel is more loaded than before, by the weight of the water, whose place this body occupies, or by that of the body itself.

In the third case, (fig. 1752.) the body only maintaining itself between two waters as long as it is kept in equilibrio by a force equal to the weight of the volume of water whose place it occupies, it is evident, that when this body is heavier than that of the same volume it must surmount the resistance opposed to it, and descend with all its remaining force, *i. e.* with the excess of its weight over that of the volume whose place it occupies; thus, bodies lose in water a part of their weight equal to that of a volume of water whose place they occupy.

A heavy body whose specific gravity is greater than that of water swims, or is maintained in equilibrio between two waters, if attached to another body whose specific gravity is greatly less than that of water: for example, if the prism C E D H (fig. 1752.) be only sunk in the water by the height C F, we may suppose all its weight united in the part C F G H, and consider the other F E D G as without weight. If to the centre of gravity of this prism a body D (fig. 1753.), of a specific gravity twice that of water, be suspended, and the volume of this body be equal to C F G H, it will cause the prism to descend to a depth C*k*, twice C F, after which they will maintain each other at rest; because the body D, weighing only half what it would in air, will be in equilibrio with the weight of a volume of water occupying F*k* M G, which is only kept in equilibrio by the weight D: the volume of the body D, and that of the part F*k* M G of the prism, having raised the surface of the water to the point which it would have reached if, instead of having plunged the body D therein, a quantity of water had been substituted, of a weight equal to that of the body, and the bottom of the vessel would be as much loaded with it as if it supported it: if the thread be cut, the body will descend, and the prism C E D H will rise to assume its natural position. If we suppose the vessel very deep, the bottom during the time of the descent of the body will be less loaded than it was, by the excess of the weight of the body over that of the volume of water whose place it occupies; for the prism having remounted to the height F*k*, the surface of the water will descend as much as if a volume of water had been abstracted equal to that of the part F*k* M G. It may then be stated as a general principle, that as long as a foreign body is supported in water, it forms a part of its total weight, and loads the bottom of the vessel with all its weight; but from the moment when it begins to descend freely till it reaches the bottom, this latter is relieved of the excess of the weight of the body over that of the volume of water whose place it occupies.

On the Equilibrium of Floatation, or the position of a floating body when its centre of gravity is in the same vertical line with the centre of gravity of the displaced fluid: when a body is in equilibrio in a fluid, its weight is always equal to that of the fluid displaced: from the equality between the weight of the body and that of the displaced fluid, the upward pressure of the fluid is exactly capable of balancing the downward tendency of the body; but unless these two forces are directly opposed to each other by passing through the same point, the solid body will have a rotary motion instead of a position of perfect equilibrium: all solids will not, however, permanently float in every case when their centres of gravity are situated in the same vertical line, for a cylinder, whose specific gravity is to that of the fluid on which it floats as 5 to 4, whose axis is to the diameter of its base as 2 to 1, its length 2 feet, and diameter 1 foot at the base, when held in the fluid with its axis in a vertical line, will sink in the fluid 18 inches; but when no longer sup-

ported, it will fall and float horizontally: a cylinder 6 inches in length, and of the same diameter, will sink 4½ inches, and in that position will float permanently: there are, consequently, different kinds of equilibrium, as that of stability, instability, and of indifference.

The stability of bodies floating on a fluid at any angle of inclination from a given position of equilibrium may be thus determined:—suppose E D H F a vertical section through the centre of gravity G of a homogeneous solid, whose figure is symmetrical with regard to the axis of motion, and that it floats on the surface H A B L of the fluid, O being the centre of gravity of the part immersed: the line G O C will be perpendicular to A B: if, by an external force, the solid is inclined through an angle K G S, it will take the position S R L M N, and the part immersed will be W R M N P:

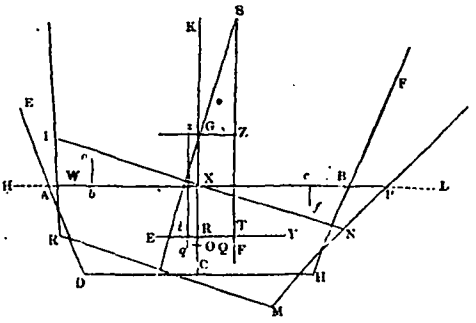


Fig. 1754

hence, as the part X W I is raised out of the water, and the corresponding and equal part X N P immersed, the centre of gravity, which would otherwise have been at E, will be transferred to the point Q: by drawing Q S parallel to G O and E Y, and Z G*z* perpendicular to S Q, it is obvious that the upward pressure of the fluid will be exerted in the line Q S, with a force equal to the weight of the body, or that of the fluid displaced, and this force will have the same tendency to turn the body round its axis of motion, as if it were applied at the point Z: to determine, then, the position which bodies assume on a fluid surface, and the stability with which they float, it is only required to find the perpendicular distances G, Z, between the two vertical lines which pass through the centre of gravity of the solid and the part immersed: as the weight of the body continues the same, the portion I X W elevated from the fluid, in consequence of the inclination, must be equal to P X N, the portion immersed: supposing *a* to represent the centre of gravity I X W, and *f* that of N X P, the centre of gravity Q will be at a distance from E corresponding to the change produced by removing the fluid I W X to the position N X P. To determine by a geometrical construction the line G Z, let fall the perpendicular *a b*, *f c*, and in the line E Y, drawn parallel to A B, take E T, so that E T : *b c* = volume I W K : volume W R M P; through T draw F T S parallel to G O, the required centre of gravity will then be somewhere in F S: and because E R : E G = sin. K G S : rad.; the line G O = E G, being supposed given, the line E R will be determined, and being taken from E T, already found, will leave E T or G Z, the perpendicular distance required.

When the body of a system is removed from its place, the corresponding motion of the common centre of gravity, estimated in any given direction, is to the motion of the body moved, and estimated in the same direction, as the weight of that body is to the weight of the whole system: considering, then, I R M N as a system of bodies, whose common centre of gravity is E, and that the body I W X, whose centre of gravity is *a*, has moved, or been transferred to N X P, whose centre of gravity is *f*, we shall have volume W R M P, or A D H P : volume I W X, or W X P = *b c* : E T, the motion of one body, and the centre of gravity of the system.

Suppose, then, V = the volume of the immersed portion of the floating body,

A = the volume N X P, or the part immersed in consequence of the inclination,

h = G O, the distance between the centre of gravity of the whole solid, and that of the part immersed,

s = to the sine of the angle of inclination K G S,

b = *b c*, the space through which A has been transferred.

Then, $b : ET = V : A$, and $ET = \frac{b \times A}{V}$;

but, E R : E G, or G O = *s* : 1, we have E R = *h s*;

consequently, $RT = ET - ER$, or $GE = \frac{bA}{V} - hs$.

When a solid body floats upon a fluid of greater specific gravity than itself, and has attained a state of equilibrium, the magnitude of the body is to that of the part immersed below the plane of *floatation*, as the simple specific gravity of the fluid is to that of the floating body: therefore, to find the magnitude of any solid so floating, subtract the

specific gravity of the solid from that of the fluid; multiply the remainder by the magnitude of the solid, and divide the product by its specific gravity for the weight to be added: or the same may be more practically expressed by multiplying the specific gravity of the fluid by the height of the body above its surface, and dividing the product by the difference between the specific gravity of the fluid and that of the solid; the quotient will give the side of the cube required.

For example, if a cube piece of oak when floating with its sides vertical, stands above the surface 12 inches, and we consider its specific gravity ·8 when water is 1, we shall have

$$\text{the length of side required} = \frac{12 \times 1}{1 - .8} = 60 \text{ inches};$$

therefore the cubical content of the body is $60 \times 60 \times 60 = 216000$ inches.

To determine how much of a Paraboloid will sink, when in a state of quiescence on the surface of a fluid, we must divide the difference between the specific gravity of the fluid and that of the solid by the specific gravity of the fluid; then from unity subtract the square root of the quotient, multiply the remainder by the axis of the parabola, and we shall obtain the height of the frustum that falls below the plane of floatation. Or, if we divide the specific gravity of the solid by that of the fluid on which it floats, and multiply the square root of the quotient by the axis of the body, the product will give the height of the part below the plane of floatation.

Floating Bodies. — If a body float on a fluid, it displaces, as we have shown, a quantity of the fluid equal to itself in weight: for since the body is supposed to remain at rest, and to retain the pressure of the fluid below it in equilibrio, it must exert by its weight a pressure downwards equal to that of the quantity of fluid which would retain the same pressure in equilibrio, or to the quantity displaced.

When the centre of gravity of the floating body is in the same vertical line with the centre of gravity of the fluid displaced, the body remains in equilibrio: if the section of a floating body made by the surface of the fluid be a parallelogram, its equilibrium will be stable or tottering according as the height of its centre of gravity, above that of the portion of the fluid displaced, is smaller or greater than one-twelfth of the cube of the breadth, divided by the area of the transverse vertical section of the immersed part.

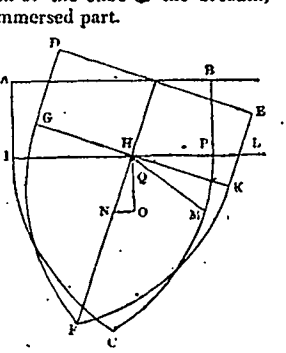


Fig 1755.

Let the body be inclined in a small degree from the position of equilibrium, A B C, into the position D E F, the triangles G H I and K H L will be equal, since the area of the section immersed must remain constant, and G K and I L will ultimately bisect each other in H. Now the centre of gravity of the section I L F is the common centre of gravity of its parts, I H M F and L M H, making K M = G I; but N, the centre of gravity of I H M F, is in the line H F bisecting it; and the common centre of gravity may be found by making N O parallel to H K or to H L, in the same ratio to the distance of the centre of gravity of L M H from H, that L M H bears to I F L. Now the distance of the centre of gravity of any triangle from the vertex being two-thirds of the line which bisects the base; in this case it is $\frac{2}{3}$ H K, and the area of the triangle L H M is H K . K P; therefore N O : $\frac{2}{3}$ H K :: H K . K P : L F I, N O = $\frac{\frac{2}{3} \text{HK} \cdot \frac{1}{2} \text{KP}}{\text{IFL}}$; but drawing O Q vertically through O, N O : N Q :: K P : H K, and N Q = $\frac{\text{NO} \cdot \text{HK}}{\text{KP}} = \frac{\frac{2}{3} \text{HK cub.}}{\text{IFL}} = \frac{1}{12} \frac{\text{IL cub.}}{\text{IFL}}$.

If therefore the centre of gravity be in Q, the body will remain in its position, or the inclination will be very small, since the result of the pressure of the fluid acts in the direction O Q; if the centre of gravity be below Q, it will descend towards the line Q O, and the body will recover its situation; if above Q, it will be overset: hence the point Q is sometimes called the centre of pressure.

Fountain of Hiero. — The fountain of Hiero is a machine by which the motion of one column of water is transmitted to another by the intervention of a bed of air separating the two: in generalising the principle on which the construction of this fountain is based, we may consider it as a machine, transmitting the motion of a liquid, A, to any other liquid, B, by the intervention of a compressible or incompressible fluid whose specific gravity is less than that of the two liquids A and B.

Fig. 1756. represents the fountain of Hiero, composed of three bases, N P Q I, D R S D, P Q E, also marked by the letters C, C′, C″. The C, C″, are filled with water, and the vessel C′ with air; the water from the vessel C falls into C′ by a tube, B D D′, and transmits its motion to a column of water, which is elevated from the vessel C″ by the tube K L; this transmission is made by the intervention of the air, which fills the vessel C′, and the tube F E H.

The bottom, P Q, of the vessel C forms a cover to the lower vessel, C″, the two only communicating by the opening A, which is closed by a plug when the vessel C″ is full of

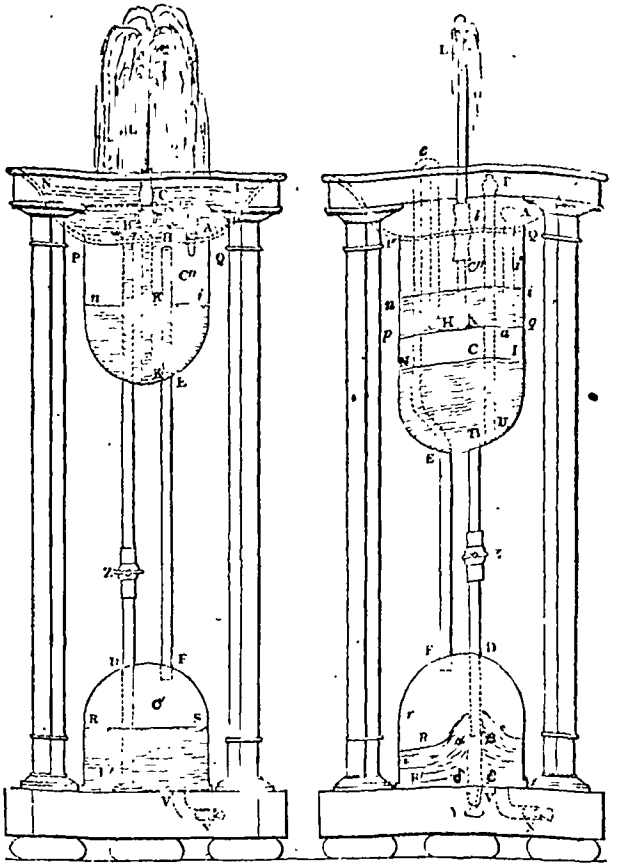


Fig. 1756. HIERO'S FOUNTAIN. Fig. 1757.

water: the vessel C″ communicates with the external air by a tube, K L, which traverses the bottom, P Q, of the vessel C, and is open at both ends.

To put this machine into play, the cock, Z, of the tube, B Z D D, is opened; the water from the vessel C flows through D′, fills the vessel C′, and compresses the air contained in it, which compression transmits itself by the tube F E H to the liquid in the vessel C′, and obliges it to rise by the tube, K L; the vessels C, C″ are emptied, and C′ is filled; N I, *n i*, R S being the levels of the water in the three vessels; the air comprised between the levels R S and *n i* is more compressed than the atmospheric air, and this increase of pressure, which we may call *p*, is measured by a column of water whose vertical height is the distance between the levels N I and R S, which is variable, the vertical distance being continually diminished. The pressure at K, the extremity of the tube K L, open at both ends, is evidently the sum of the two pressures, of which one is equal to *p*, and the other *p′* is measured by a column of water of the variable height K K, K K, being the vertical distance from the extremity, K of the tube to the level of the water, *n i*, in the vessel C″; therefore the pressure at K, which elevates the water in the tube K L, is variable, because it depends on two other pressures *p* and *p′* which decrease every moment. If the level *n i* descended to K, the water would rise in the tube K L, to a height equal to the vertical distance of the two levels, N I and R S, corresponding to the level *n i*, which we suppose has descended to K; but at the moment when the machine is put into play, the water would elevate itself in the tube K L to a height equal to the vertical distance of the extremity D′ of the tube B D′, from the first level N I; then the force which elevates the water in the tube K L would decrease;

and its limits are the minimum and maximum pressures which correspond to the two heights to which the water can elevate itself in the tube K L, at the beginning and end of the movement.

When the vessel C″ is empty the cock Z is closed; the vessel C is then emptied by the pipe V X, which is closed by a plug, X, removable at pleasure; the vessels C, C″ are filled as before stated, and the machine is ready to play again.

The tube B D′, by which the water falls from C to C″ might terminate at D; the pressure of the air of the vessel C′ would then only depend on the height of the level N I above the point D; as long as the tube B D is prolonged to D, this pressure depends on the distance between the two variable levels, N I and R S.

Supposing that instead of filling the vessels C and C″ with water, some other liquid were substituted, as mercury, and the air which the vessel C′ and the tube F H contain replaced by another incompressible fluid, such as water, the pressure of the water would replace that of the air, and the mercury in the vessel C produce in falling a force capable of elevating that in the vessel C″ in the tube K L. The incompressibility of water transmits the moving power, by increasing the effect for the power employed to compress the air which would remain in the vessel C, and which is gained the instant that the tube K L no longer contains water, as the air compressed in the vessel C′ mixes with the atmospheric air by the tube K L, and produces no useful effect.

The invention of this machine is attributed to Hiero, who lived 100 years B.C., and it has been constructed on a large scale for emptying water from the mines at Schemnitz in Hungary; its principle, modified by Gerard, has been applied to elevate the oil in hydrostatic lamps. In the machine of Detranville, water is raised by the rarefaction of the air; in the fountain of Hiero the same effect is produced by condensing it.

Gerard's have this advantage over the ordinary Argand lamps, that the reservoir of oil being below the focus of the lamp, it does not throw a shadow on the surrounding objects.

Fig. 1757. represents the new fountain of Hiero as applied to hydrostatic lamps: $p\,q$ E is a vessel filled with oil, which falls through a tube B D Y in the vessel R D S, which is then full of air; these two vessels correspond with those marked C and C′ in fig. 1756.: they are designated by the same letters in fig. 1757.: the vessel C only communicates with the external air by the tube U T, which traverses the cover $p\,q$; the oil cannot escape from the vessel by the tube B D Y, except when the air enters by the tube T U, so that the elastic force of the air, $p\,q$ N I, and the pressure of the liquid, N I U, always equalise the pressure of the atmospheric air which fills the tube U T.

Drinking glasses for birds and inkstands are constructed on this principle of equilibrium. The tube B D Y is plunged below Y into a cylindrical vessel $\alpha\beta\delta\epsilon$ filled with oil and open above, while it is closed below by the plug Y; the height from which the oil of the vessel C falls into C″ is constant and equal, B Y, whatever may be the heights of the level N I and R S in C and C′.

The vessel C′ communicates with another, C″, full of a liquid similar to that in C′; this communication is established by means of a tube of any form F E e H, which passes through the cover P Q of the vessel C″, terminating at the bottom H of this vessel. The vessel C′ communicates with the external air by a tube L K, which is prolonged to the bottom of the vessel; the orifices H and K of these two tubes are in the same line with the level H K.

If we suppose the vessel P $p\,q$ Q or C″ of a height P p less than B Y, the pressure of the fluid P H Q on the orifice H cannot equalise the air contained in the vessel C′ and in the tube F e H; this air being compressed by the weight of the atmosphere and a column of liquid of the height B y, it will leave the tube F E H by the orifice H, and occupy a space P Q $n\,i$ in the upper part of the vessel P $p\,q$ Q or C″; the liquid which the air has replaced will elevate itself in the tube K L.

When the air contained in the vessels C′, C″ is in equilibrio, the height K L, to which the liquid will elevate itself, will be equal to the constant height B y: the pressure on the extremities K and H of the tubes R L and H c E F are equal; that at H results from the pressure of the liquid $n\,i$ H, and the elastic force of the air contained in the vessel C′ and the tube F e H; but this elastic force has for its measure the height B Y of the liquid; the pressure at the extremity of the tube L K is due to the same height B Y, and by giving to K L a height less than B Y, the liquid of the vessel C′ would rise in the tube K L by constant force of pressure.

In the hypothesis of the ascensional movement of the air contained in the vessel C′ and the tube F H, the air of this tube is less compressed at H than at F, otherwise the ascensional movement would be impossible; but to fulfil the object proposed it suffices that the compression of the air at H be constant: by giving to the tube F H convenient form and dimensions, the vessel C″ may be placed in any position with regard to the vessel C.

When the vessels C and C″ are empty, there are several methods of refilling them: fig. 1757. indicates the following; the tube K L is composed of two parts, K l, l L, which are screwed together at $n\,l$; when they are separated the oil is poured through the opening l,

and the air from the vessel C′ or P pq Q escapes by the same opening: a tube A a traverses the cover P Q, and the bottom pq of the vessel C″; oil is poured through the orifice A; it flows through the other orifice a, and falls into the vessel C or pq U; the air of the vessel escapes through the same orifice, u, of the tube A a, and as we suppose the cock Z closed, the vessel C is filled.

It does not suffice to fill the two vessels C and C″; we must empty the vessel C′, the bottom of which communicates with a pipe V X closed by a plug; we remove the plug and the liquid runs out; but at the same time the air must introduce itself, which it does in two ways, for it may enter by the tube H e F before we have filled the vessel C′, or by the cup $a\beta\delta\epsilon$, which is closed by a plug Y removable at pleasure.

Fig. 1757. is the form which Girard presented to the Polytechnic School. Of the three levels N I, ni, R S, in the three vessels C, C′, C″, two being given, the third is found; knowing the volumes of these vessels, we find by calculation the relation between the quantities which determine the position of their level lines.

Description of the Hydraulic Ram.—The water from a source enters at A with an acquired velocity due to the height of the fall, flows through the conduit-pipe A B, which

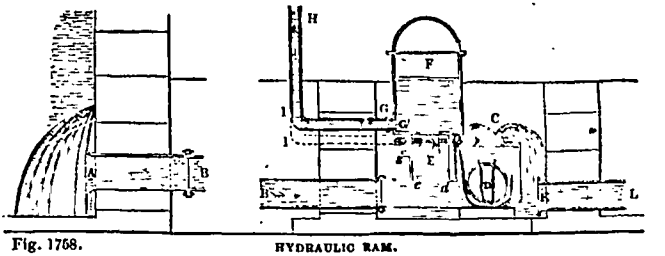


Fig. 1758. HYDRAULIC RAM.

is exchanged at A, and inclined with a fall of at least 27 millimetres in 2 metres; it escapes by an orifice C, which may be closed at pleasure by a valve. A reservoir of air, F, is united by means of a cylindrical pipe, $abcd$, to the conduit pipe, B D; at the centre of the bottom of the reservoir F is a circular orifice, to which a small cylindrical support is adapted, whose extremity, E, is furnished with a valve; s is another valve destined to maintain the air in the reservoir F, and in the space mn, comprised between the pipe $abcd$, and the small support E of the valve; G I H is an ascension pipe, which rises from G in the air reservoir F. The pipe A B, B C, by which the water flows from the source, is called the body of the ram; the tube G I H, through which the water elevates itself above the source, the ascension pipe; of the two valves D and E, which close the orifices C and E, the first is the flowing or stopping valve, and the second the ascension valve; these valves are hollow balls, D and E, which are retained by muzzles, and they do not weigh more than twice the volume of water they displace; the extremity of the body of the ram, which carries the valves and reservoir of air, F, is termed the head.

This machine acts in the following manner: the water through the orifice C acquires a velocity due to the height of the fall; it obliges the ball D to leave its muzzle, and elevate itself to the orifice C, which is terminated by round pieces of leather, or tarred cloth, to which the ball applies itself exactly; as soon as the efflux through this orifice stops, the water raises the ball E, which closes the orifice E of the air reservoir F, and flows at the same time into this reservoir and into the ascension pipe G I H, losing the velocity which it had at the moment when the opening C was closed; the balls D and E then fall by their own weight, one into its muzzle, the other into the orifice E; the water from the source begins again to flow through the orifice C, the valve D again closes, and the same effects are produced. The revolution of the ram commences when the stopping valve D ceases to be applied to the orifice C; it ends when this valve returns to the same position: in this revolution there are four distinct operations; in the first, the water, by flowing through the orifice C, acquires a part of the velocity due to the height of the falls, and the stopping valve D closes; in the second, the stopping and ascension valves are closed, and the elastic bodies, whether metals or air, are compressed; in the third, the ascension valve opens the air of the reservoir F, which is compressed; the water elevates itself in the ascension pipe G, the ascension valve closes, and the stopping valve does not re-open; in the fourth, the elastic bodies compressed in the second re-act, the ascension valve remains in its place, and the stopping valve, no longer applied to the orifice C, falls into its muzzle. With regard to the duration of time occupied by these four operations, we may observe that in the first, if the distance from the stopping valve D to the orifice C, and the weight of the valve, be increased, the greater will be the velocity of the water which flows through the orifice C, to raise the valve D and apply it to the orifice C: for each position of the valve, at the

bottom of its muzzle, the quantity of water elevated in a certain time is measured, taken as unity through the ascending tube G I H; and by varying the distance from the valve D to the orifice C, the water in the body of the ram receives the velocity which corresponds to the maximum effect of the machine.

In the second operation, the air contained in the space M N is compressed by the force developed in the first operation, which also drives the water through the orifice E, in the reservoir of air F, and into the ascension pipe H, when the valve E immediately falls by its own weight from its muzzle into the orifice E, and the stopping plug D again closes the orifice C: the two valves being closed, the air compressed at *m n* reacts, and although the time of this reaction is scarcely perceptible, the effects resulting from it have a great influence on the play of the ram; the reaction obliging the water to return from the head of the ram towards the source, which forms a void at the extremity of the head; the atmosphere presses on the stopping valve D, the orifice C opens, and the water from the source contained in the body of the ram A B C, in flowing through this orifice, reassumes its primitive velocity: the water continues to elevate itself in the ascension pipe G H, by the elasticity of the air compressed in the reservoir F, which acts on the water and forces it to rise. The motion of the ascending column of water communicates itself to the air of the reservoir F, which would soon be emptied if a fresh portion were not introduced into it at each revolution of the ram: the little channel *s*, closed by a valve, conducts this air; the valve opens from the exterior towards the interior of the ram, in consequence of the void formed by the fourth operation, and a certain volume of atmospheric air enters the little cylinder *a b c d*, situate below the reservoir E, into which it is driven, a portion being arrested in the space *m n*, and forming the elastic body we call a bed of air; it is the reaction of this compressed air which causes the water contained in the body of the ram to return to the source.

It results from this description of the hydraulic ram, that its principal parts are, 1st, the body of the ram; 2dly, the head which comprises the stopping-valve, the ascension-valve, the air-valve, the reservoir, and the bed of air; 3dly, the ascension-pipe. We do not, as yet, know the dimensions which should be given to the different parts of the ram, in order to ensure the greatest effect possible from a source of water. An experiment was made at Marly, which showed the application of the hydraulic ram on a large scale; the mean fall was 1·62 metres; this height is the mean difference between the levels above and below the Seine: the body of the ram which was constructed was 33 centimetres internal diameter; the vertical height to which it ought to have elevated water is 155·5 metres: it is principally for these large rams that recourse must be had to experiment, and to make a great number of observations on the form, dimensions, and general disposition of the parts which compose them.

As for the lesser rams, experience has brought them to a great degree of perfection, and those who use them praise them highly. A mechanic who should compare the quantities of water expended to the quantity elevated would conclude that the ram was the best hydraulic machine; it has, above most others, the advantage of being applicable to the least abundant sources of water; the least fillet of water can move a ram by giving it dimensions coincident with the moving power: with regard to economy there is no machine which requires less expense for its first establishment and maintenance.

To give a precise idea of the dimensions of rams which have been employed, we must refer to those which have been constructed, 1st, at Lyons, by Fay Sothonay, Mayor of Lyons; 2nd, at the bleaching-ground of Turquet, near Senlis; 3rd, at Clermont Cisé, under the sub-prefecture of Larochefoucauld.'

The source of Fay Sothonay gives 84 litres per minute; the fall of this source is 10·6 metres: by taking a cube diameter of water elevated 1 mètre as the unit of force, the power of the source during one minute will be expressed by 890. The body of the ram is 54 millimetres diameter, and the length 32·5 metres. The ascension tube was 227 metres long; it furnished 17 litres per minute. 'The water was elevated to a vertical height of 34·1 metres; thus the force transmitted by the ram during one minute is expressed by 579; the relation of this number to the expenditure of power in one minute is $\frac{579}{890} = \frac{65}{100}$.

The body of Turquet's ram was cast-iron, ·0203 metres in diameter, and the length about 8 metres; it elevated water to a vertical height of 4·55 metres; the quantity so elevated in one minute was expressed by 1224; the source furnished in the same time 1987 litres; its fall was 0·979 metres; its force in one minute was 1945. The relation of the transmitted force to that expended was then $\frac{1224}{1913} = \frac{63}{100}$.

Delcassan, who executed Turquet's ram, has verified by experiment the importance of giving to the tubes which form the body of the ram, as well as to the wood or stone supports of the tubes, the greatest solidity; he conceived that the force employed to move the body of the ram or its support is lost for the effect we wish to obtain. Having remarked that, by increasing the head of the ram, the machine would elevate a greater

quantity of water, he melted lead on the body of the machine, until the weight of the lead ceased to increase the product of the machine.

The body of the ram established near Clermont Oise is 27 millimètres diameter, and 33 metres long; it is on the side of a mountain with a fall of 7 metres in 33. The ascension pipe is 14 millimetres in diameter, and 420 metres long; it furnishes 1460 litres of water in 24 hours; the water is elevated to a vertical height of 60 metres; the force transmitted by the ram in 24 hours is expressed by 84000.

The source furnishes in 24 hours 17,878 litres of water, or 19,200 pints; this water falls 7 metres in going through the whole length of the body of the ram, which is 33 metres; the force expended in 24 hours is 125146; the relation of the force transmitted to the force expended is $\frac{84000}{125146} = \frac{67}{100}$.

Montgolfier, Junior, established at *Mello*, near Clermont, an hydraulic ram of cast-iron, 1450 kilogrammes in weight: the length of its body is 33 metres (100 feet), its diameter 11 centimetres (4 inches), and the thickness of each pipe 14 millimetres (6 lines); the head of the ram separately weighs 200 kilogrammes. There were 7 balls or stopping valves, each 4 centimetres diameter, disposed as is shown at N N', on 7 orifices piercèd in a single circular disc, as seen in the figures on page 1163; the ball or ascension valve is of the same diameter; the ram makes 60 strokes per minute; the volume of the reservoir of air is about 20 times that of the quantity of water elevated at every stroke. The source is 140 litres per minute, and its fall is 11·37 metres (35 feet): the water is elevated 59·44 metres (183 feet) above the head of the ram, and the quantity of water raised is 17¼ litres per minute. Taking the kilogramme elevated a metre as unity, the product and expenditure in a minute are expressed by the numbers 1040 and 1592, whose nearest relation is $\frac{65}{100}$.

These examples prove that the force transmitted by the ram is at least $\frac{68}{100}$ of that employed to move it; we know of no other water-machine which transmits so considerable a part of the action of the mover applied to it.

Siphon Ram. — When water is made to pass by means of a siphon from one place to another less elevated, the column of water fills the interior of the siphon; but if the summit communicates by a small aperture with the external air, the column separates into two parts which flow through the two branches of the siphon. There are few machines more useful and simple than the siphon: the cut represents one executed for the Polytechnic School at Paris.

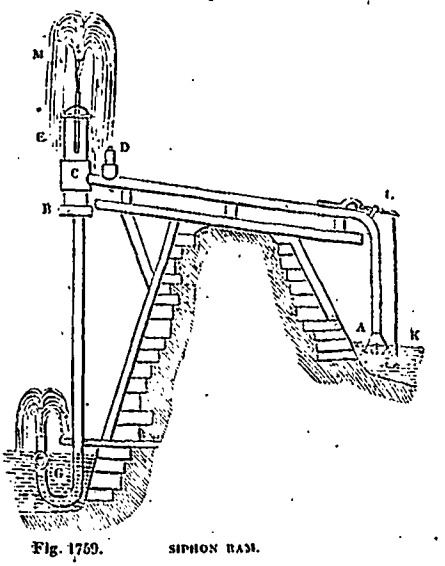


Fig. 1759. SIPHON RAM.

A L C G is a siphon transporting water from A to G; on the long branch G B is a ram's head with two valves at C of flowing and ascension, and above them a reservoir of air; a cock is placed at G, and a valve at K, which opens and shuts by means of a lever, the extremity of which is fixed at L when this valve is open.

To work the siphon, the cock G and the valve K are shut; water is poured through the pipe D; the air escapes by the same pipe both out of the vertical branch G B, and that inclined to the horizon, D L; the pipe D being closed by a plug, the cock G and the valve K are opened; the water which flows through the siphon from A to G shuts the flowing valve C, opens the ascension valve E, and escapes at M in a jet of water, or raises itself in the ascension pipe screwed on the air reservoir above C.

Suction Ram. — A source of water flows through the tube A B D K, and it is proposed to elevate by its means the water from the well M N G; in the interior of the branch P Q of the tube is a ball valve C, to shut the orifice D of the same tube: near this orifice D is a suction tube E, composed of two parts, E F, G G', united by an air reservoir H H, and at this end of the tube is a valve opening from below upwards: the water from the source, in flowing through the orifice K, acquires a velocity arising from the fall; the valve C, sustained by the column of water produced by this velocity, closes the orifice D by adhering to the round pieces of leather or cloth shaped into a hollow sphere; the column D E K continues its movement towards K; the void formed in the tube D E K, and the

atmospheric pressure elevates the water in the well by the suction pipe: the height to which the water rises depends on the velocity with which it flows from the source through the orifice K: the object of the dilated air reservoir H H is to maintain the motion of the ascending column G' G.

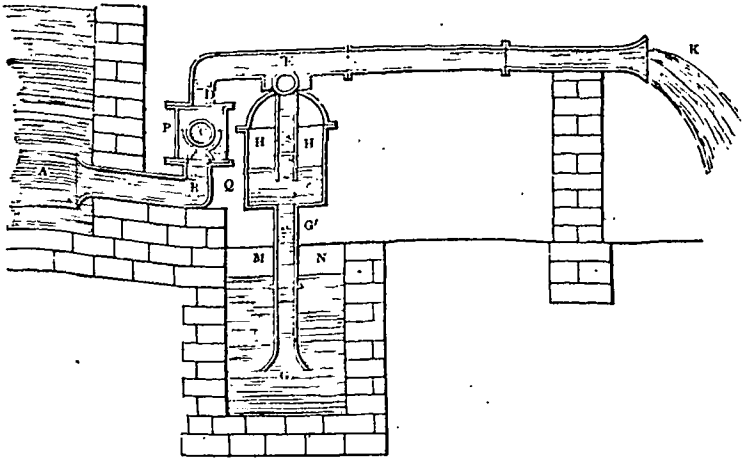


Fig. 1760. SUCTION RAM.

We must now refer to what was before said on the return of the water, which the body of the ram contained, towards its source, and we shall easily conceive how this may become a suction ram: if the space *m n*, (fig. 1758.) of the bed of air communicates by a tube with the reservoir of water placed below the body of the ram, at each re-action of the bed of air the water of the reservoir would elevate itself, to equalise the elastic force of the air contained in the space *m n* and the atmospheric air; and if the distance of the lower reservoir from the body of the ram is not too considerable, the water of this reservoir would flow with the water of the source which puts the ram in motion: when we estimate the total effect of the ram, we must then have regard both to the water elevated by the ascension pipe and that elevated by the return of the ram.

Example of this double Effect. — Montgolfier had placed a ram's head at the extremity of a cast-iron pipe 54 millimetres (2 inches) in diameter, and 19·5 metres (60 feet) in length; this tube expended 65 litres of water per minute, falling from 3·25 metres (10 feet); taking for unity a cube decimetre or litre of water elevated 1 decimetre, the power expended in a minute by the body of the ram was 2212. At each pulsation of the active column of the ram, which was followed by the return of the flowing valve to its orifice, 142·44 cube centimetres of water were elevated by the ascension tube 18·516 metres, the interval between the two pulsations being 1 second; the ascension tube furnished 8·546 litres of water in a minute to a vertical height of 18·516 metres; thus the force transmitted by the ascension tube is expressed by the number 1582·37. To this first effect we must add that which we obtained from the return of the ram; a suction tube which should arise from the space occupied by the bed of air, plunged in a reservoir distant 0·975 metres from this bed, all the water in this ascension tube would be furnished by the suction tube; therefore at each minute the return of the ram would elevate 8·546 litres of water to a vertical height of 0·975 metres. This effect is the measure of a force of 83·32, which being added to the first effect, 1582·37, gives for the total effect of the ram in one minute 1665·65; but the force expended in the same time is 22·12; the relation $\frac{75}{100}$ of these two numbers is still greater than in the preceding examples.

Montgolfier projected at Marly a ram, which was at the same time a siphon and suction: the siphon form appeared to him most preferable, because it placed the greater part of the pipes of the body of the ram out of the water; the suction tube emptied the water filtered by a chest placed on the bed of the river, and there was no fear of a deposit of sand on the valves or their orifices.

Fig. 1761. shows, 1st, a system, N', of seven valves and seven orifices; 2d, a disc M', pierced with holes, through which the water enters the air reservoir L, fig. 1762.; in general the number and size of the flowing orifices determine the relation of the velocity of the water in the body of the ram, and its issue through each orifice.

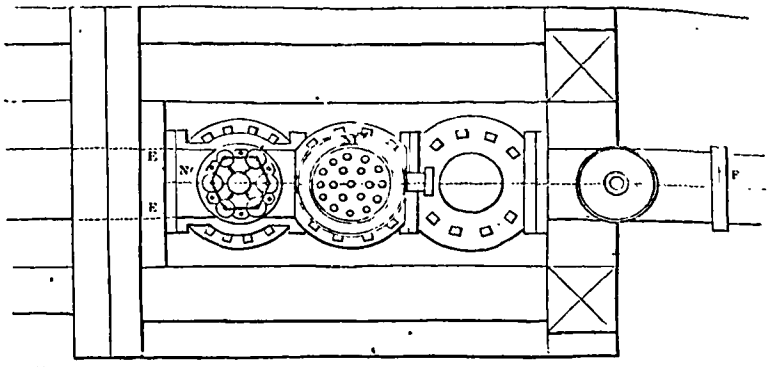


Fig. 1761. PLAN OF SIPHON AND SUCTION RAM.

Fig. 1762. K H B B is the branch of a siphon which leads the water from the source; it flows through the apertures N, N, N, falls into the cistern P Q S R, and joins the lower waters,

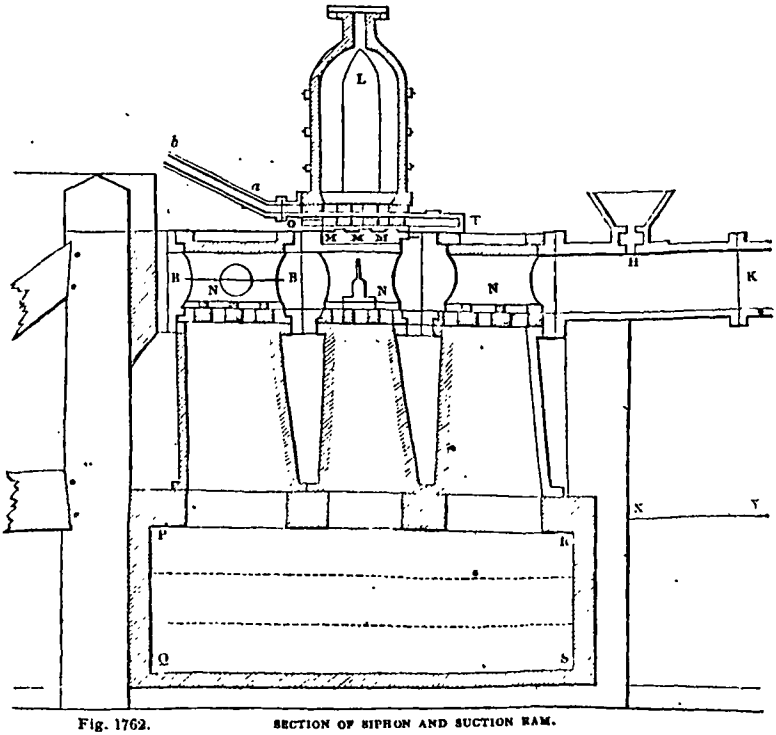


Fig. 1762. SECTION OF SIPHON AND SUCTION RAM.

X Y; H is a funnel, garnished with a stop-cock to feed the siphon; T is the suction tube, which arises from above the ascension valves M, M, M; below these same valves is a wooden float, which is lowered by the action of the air-bed, and which rises by the action of the water in the body of the ram against the ascension valves: the space in which the floater moves is called the lift of the floater. O is the small canal through which the outer air enters the reservoir L; *a b* is the ascension tube.

Fig. 1763. shows on a larger scale, 1st, the ascension valve; 2d, the air valve N O, which serves to maintain the air in the reservoir L; 3d, the floater's lift, Z. In the ram executed at Marly there is no suction tube, but the siphon form is preserved, as in the first project; the inconveniences which result from this form for rams of a large size were difficult to foresee: in small rams it is necessary to introduce the external air into the space

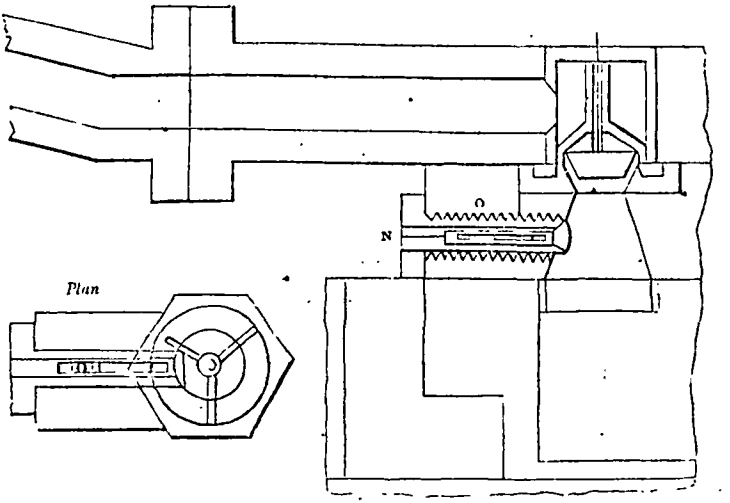


Fig. 1763. SECTION OF SIPHON AND SUCTION RAM.

occupied by the bed and reservoir of air; the contrary takes place in the great ram siphon, such as that established at Marly; the effect of the ram's return has a tendency to introduce air through the joints of the tubes or cistern, and, as the junction cannot be perfectly exact, this air enters in so great a quantity that the whole force of the ram is required to compress it.

In the first trials Montgolfier made with this machine he placed the ascension valve in the interior of the ascension tube, at some distance from the body of the ram, and filled the ascension tube with water, to put the ram more easily into motion; the atmospheric air, however, retained between the ascension valve and the column of water in the body of the ram, occupied so considerable a volume, as to destroy the useful effect of the ram, the active column being employed to compress this air: an inconvenience of this sort presented itself when the siphon ram at Marly was experimented on.

Great Siphon for drawing off Water, as employed at Metz in repairing a dyke constructed on the Moselle: it raised the water from the head of the dyke, and discharged it into the

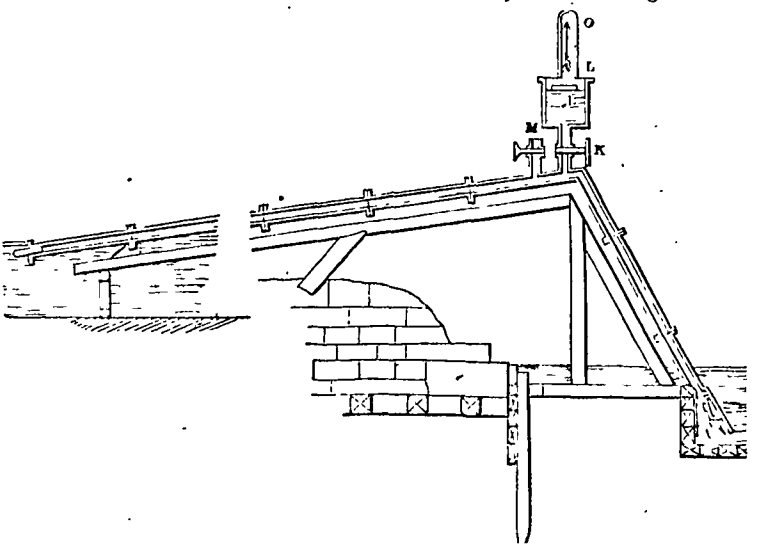


Fig. 1764.

river, the difference of level being 1 metre: the long branch of the siphon was 30 metres, and the diameter 8 centimetres; the two extremities of the siphon were closed with wooden plugs: the siphon was filled with water through the funnel I; the air escaped by the cock M; when full of water this cock was closed, a cover L O was screwed on the funnel, and the cock K was kept open; the velocity of the water in the siphon not being very great, the air brought up by this water accumulated at the highest point of the siphon, and lodged in the funnel I: to let it out, the cock K was closed, the cover L O taken off, the funnel filled with water, after which the cock K was again opened, and the cover screwed on the funnel; the part L O of the cover is a glass tube, which contains a needle supported by a float to show when the funnel I must be filled with water.

Verra's Machine. — This machine is a species of chain-pump or endless rope turning on pulleys, and drawing a certain quantity of water with it; the pulleys, P P and P′ P′, are traversed by parallel axes A, B, and united by endless ropes two and two: the pulleys P, P′, plunge into the water, which is to be elevated, and by turning the handle E F, the cord which passes over the pulleys D, H, and C turns the axle A B, and the pulleys P, P′; the endless rope that unites the pulleys acquires, by simple friction, a continuous motion, which communicates itself to the water in the lower reservoir Z M, and forces it into the upper reservoir N O. The play of this machine chiefly depends on the tension of the endless ropes by which the required friction is obtained: if this be too great, the pulleys P, P′, cannot turn; if too slight, the pulleys slip on the ropes, and do not communicate any motion to them. The adherence of the water to the cords favours the transmission of their motion to the molecules of water.

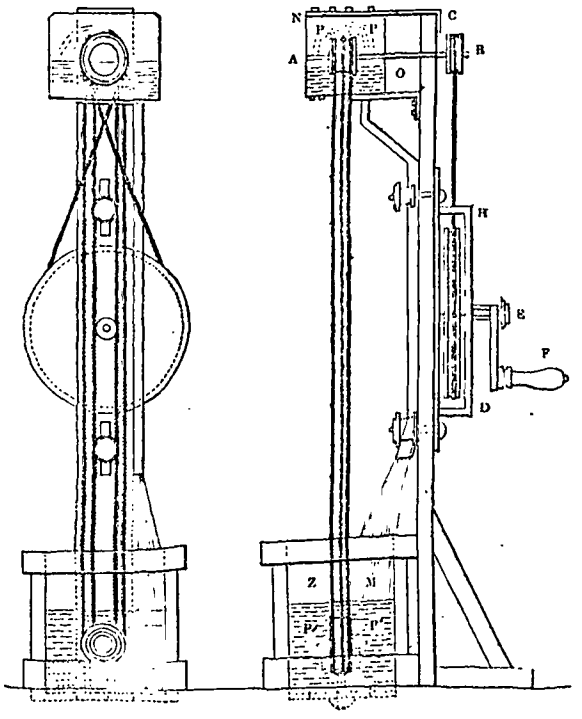


Fig 1765. VERRA'S MACHINE.

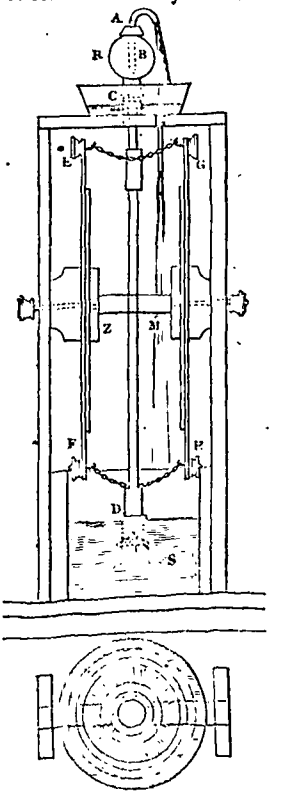


Fig. 1766. HYDRAULIC CANE.

Hydraulic Cane. — This consists of a hollow tube A B C D furnished with a valve D in the lower part; the extremity of the tube dips into water, and an alternate rectilinear motion is given to it; the water is elevated, and issues through the upper extremity A; to render the motion of the column continuous, an air reservoir, R, is added, which separates the two parts of the tube A B, C D. The cane or tube is fixed by cords to the wooden *spring-blocks* E F, G H, fixed to the wall of a well by a cross-piece Z M: as a substitute for these spring-blocks, a pole may be placed from an edifice at some distance from the reservoir containing the water to be raised. The play of this machine depends principally

on the velocity with which the tube C D mounts and descends, and it should be sufficient to allow of the water preserving an upward motion in sliding on the sides of the tube, although the tube continues to descend.

Machine of Vialon. — On a movable axis A B two helicoidal tubes are placed, whose central lines are helices of the same number of turns drawn on the same cylinder, but placed in an opposite direction; each extremity E, F, of the tubes is furnished with valves which open from without inwards; by means of a lever C D fixed to the axle A B, an alternate circular motion is given to the tubes; at each impulse of the water on one of the valves it opens and allows the water to rise, at the same time the other valve closes, and retains the water already elevated; the two helicoidal tubes unite in one, H K L, by which the water, when elevated, flows out. This machine and the hydraulic cane are constructed on the same principle; the tubes in both are terminated by a valve; they differ in the manner of transmitting the motion to the tubes, the hydraulic cane having an alternate rectilineal motion, and the machine of Vialon, which is composed of two hydraulic canes, has an alternate circular motion.

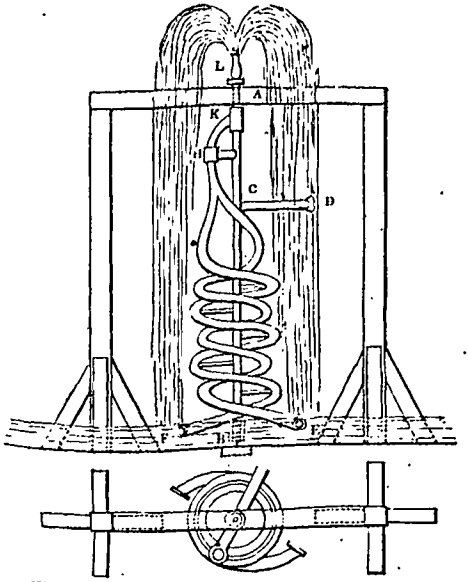


Fig. 1767. MACHINE OF VIALON.

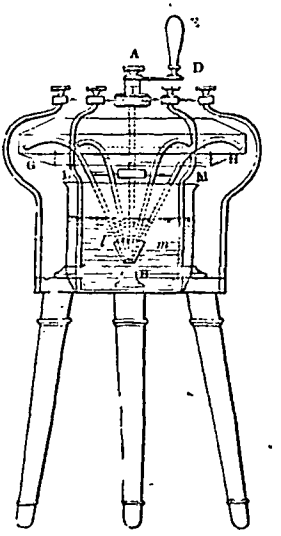


Fig. 1768. CENTRIFUGAL FORCE MACHINE.

Centrifugal Force Machine. — A B is a vertical axis movable on two gudgeons, and turned by means of a winch A D E; hollow tubes are ranged round this axis like truncated cones, the small base of which, *lm*, plunges into water; they are fixed on the circumferences of circles *lm*, L M, and are curved at the upper part, so that the water which escapes at the extremity of the tubes falls into a circular basin parallel to the circle L M: when the axis A B is turned, the water, to escape from the small circle *lm*, rises to the extremities of the tubes, through which it falls into the vessel G H. Girard made a report to the Academy, 9th December, 1816, on a centrifugal pump, constructed on the same principle, by Jorge: his pump, as first described in the collection of the Academy machines, 1732, was composed of a vertical tube, and transversal branches fixed thereon, movable round the same gudgeons. Jorge's modification consisted in fixing the suction pipe, and only putting the transversal branches of the apparatus in motion above it: the inertia which the moving power had to overcome was thus reduced to that of the portion of the machine which it is indispensible to put in motion, and besides has the very great advantage of allowing the suction pipe to be inclined at pleasure, or of giving it any form, and thus enabling it to be used in localities which would not permit of vertical suction tubes.

Archimedean Screw. — The newel and the barrel of the Archimedean screw are bounded by right cylindrical surfaces with circular bases, having a common axis: the threads of the screw are comprised between the newel and the barrel, and their threads are generated by movable right lines always perpendicular to the axis of the screw; these right lines rest in helices of the same number of turns as are drawn on the internal cylinder of the barrel, and which intersect the edges of the cylinder at an angle of 45°; the distance between the two points of the circle at which the helices begin determines the thickness of the threads: here are generally three or four rows of similar fillets on the same newel, at the upper

extremity of which is a winch, and at the lower a gudgeon; the handle and gudgeon rest on square wooden blocks. When the Archimedean screw is applied to emptying water, the lower end is plunged into it by inclining the axle at a certain angle, the limit of which must be determined geometrically; the winch is turned, taking care that its rotation is in a contrary direction to that of the generating point of the helices, which are drawn on the exterior, and serve as guides to the generating lines of the fillets. The barrel is formed of staves strongly bound together by iron hoops, the staves sufficiently close to allow of no water passing, but the atmospheric air penetrates the joints, so that the interior air between the fillets of the screw is always of the same density as the outer: if the thickness of the fillet be disregarded, we may consider it as composed of helices drawn on parallel cylinders, having for their common axis that of the screw; these helices having the same number of turns, their bases being the circles of the cylinders on which they are drawn, the common axis of these cylinders is inclined to the horizontal plane of the water level; the limit of this inclination depends on the angle made by the tangents of each helix with the same plane of the water level: each helix may thus be considered as the element of a fillet, or a small hollow channel whose origin is at the orifice at which the water introduces itself: having drawn through this orifice a tangent to the helix, we may suppose it prolonged to the lower part of the screw as a right tube, through which the water may introduce itself into the helicial tube: if the screw be turned on its axis, the right tube will engender an hyperboloid of revolution, the common point of the two tubes, of which one is straight, and the other spiral, and the point placed at the extremity of the straight tube would describe two circles; the right tube in all its positions would rest on two points in these two circles, and it is on the position of these two points, with regard to

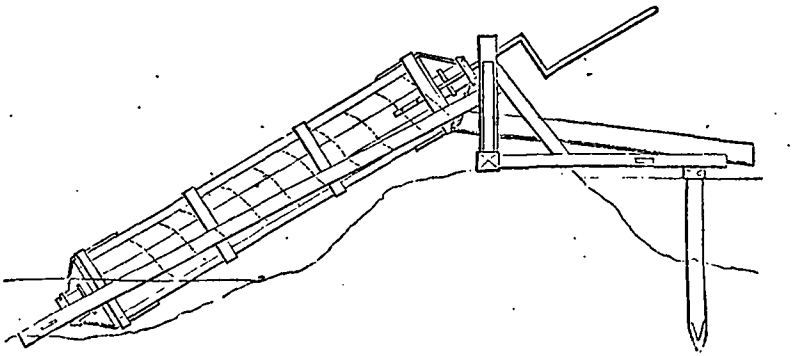


Fig. 1769. ARCHIMEDEAN SCREW.

the level plane, that the introduction of water into the right tube depends; for it is necessary that the extremity of this tube should be less elevated than the point in which it touches the helicial tube, in order that the water may slide on the tangent to the helix as on an inclined plane; there is, consequently, a necessary relation between the inclination of the axis of the screw and the tangents to the helices of its threads, which induces the water to rise: this relation determines the limit of the inclination of the screw's axis with regard to the level of the water. Suppose the orifice of the extreme helix, or the element of the fillet farthest from the axis of the screw, constantly plunged in water, while the screw turns on its axis, the right line, which touches the helix at its origin, will, in turning at the same time as the screw, generate an hyperboloid of revolution; a parallel to this right line, drawn through any point of the axis, would generate a right cone, the asymtote of the hyperboloid of revolution; if through the summit of this right cone, a plane parallel to the level of the water be drawn, either this plane would not touch the cone, or it would cut it at the two edges, or be in a tangent thereto: supposing it a tangent, it would make with the axis of the screw an angle which will be the limit of inclination of this axis with the horizontal plane, for if this inclination were increased, there would be no position of the extreme helix in which the water could introduce itself; the middle helices, that is to say, those nearest the newel, whose orifices would turn in the water, could not, *à fortiori*, receive any portion of this water, and no useful effect would be obtained from the motion of the whole screw.

In Holland the screw is constructed without a barrel, and the fillets turn in a fixed portion of the hollow cylinder, the lower extremity of which, as well as that of the screw, plunges in the water to be elevated, which fills the capacity of the hollow cylinder, and escapes at its upper extremity.

The Dutch screws are generally of large dimensions, the inner diameter of the hollow cylinder being about seventeen decimetres: they are moved by the wind, and the same windmill turns several.

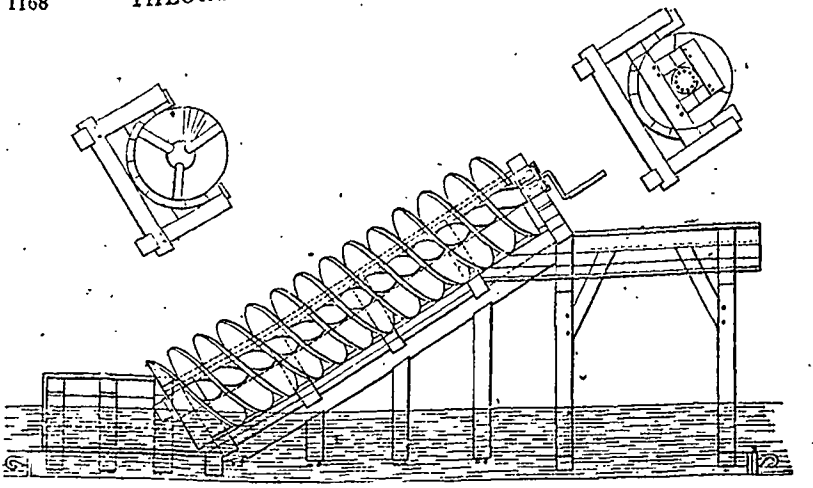


Fig. 1770.

It has been proposed to employ a fall of water to turn the Archimedean screw, by adding to the extremity of the barrel a second screw, having the barrel as its newel, and its fillets inclined in a direction contrary to those of the first. This idea was suggested by the Marquis of Worcester in his "Century of Inventions."

Calculation of the Effects of the Archimedean Screw. — The first of the two following experiments was made by Lamandé. The screw was 5·85 metres long, and 0·49 metres diameter; it was turned by two relays of men, working alternately two hours in succession: each relay consisted of 9 men; the winch made 40 turns per minute. The quantity of water elevated in an hour was 45 cube metres, and the height was 3·3 metres: the 18 men in two relays elevated in 10 hours' daily labour 450 cube metres of water 3·3 metres, or 1485 cube metres 1 metre, which gives for the measure of a man's daily work 82 units of a cube metre of water elevated 1 metre, a power nearly equal to that of a man employed in driving piles.

The following experiment gives 10 units more per man for the useful effect of the screw: six men worked six hours a day; the screw made 35 turns per minute; they elevated in one minute 765 litres to 2 metres, or 91·8 cube metres of water to 1 metre.

The motion given to the water beyond the screw consumed a great part of the moving power ineffectually, and the less the screw plunges into the water, the more its useful effect will increase with relation to the power employed in turning it. The external motion is one cause of the loss of power, which increases with the dimensions of the screw. The same observation has been made with regard to screws for blowing. These machines have externally the form of a short drum, whose diameter is very great in comparison with the ordinary barrel of the screw; the part plunged in a reservoir of water impresses on it a motion which has no effect in relation to the object required.

Suction Pump. — The simple suction pump consists of two pipes A B, C D, (fig. 1771.) the diameter of the second being much greater than that of the first, united by two flanges E, F, cast with the pipes, pierced with four holes to admit the screws C, C, which are fitted with nuts, to screw the flanges together, between which the two roundles of leather are placed. The pipe A B, which dips in the water to be raised, Y Z, is called the suction pipe; its lower extremity is slightly widened, to admit the water more freely; at A A is a metal plate pierced with several holes that the water may not carry any dirt with it. The pipe, C D, generally of copper or brass, is called the barrel; it is well polished inside to enable the piston to work easily, it being desirable that the friction should be diminished as much as possible.

The piston is an inverted truncated cone, O P L K, the base of which is surrounded by a leather band fixed by one or two rows of tacks driven close together; this band should be slightly funnel-shaped at the upper part, and fit the pump-barrel tightly where the piston is introduced, the diameter of which should be two-twelfths of an inch less. These kinds of pistons are generally of hornbeam or alder, being less subject to split than other wood; iron rings are fitted to their two bases to give great durability. The piston has a hole through its centre, M, closed with a valve, N, of leather, attached to the wood by a tail serving as a hinge; the valve when closed should exceed by half an inch the circumference of the hole, and to fit more exactly, it is loaded with a plate of lead; it has also a fork O Q P, to which an iron rod, R, is attached.

In the middle, E F, of the junction of the pump-barrel with the suction pipe is another

hole H closed by a second valve G, and cut in a copper plate which is united to the suction pipe A B, and cast at the same time. The diameter E F exceeding the suction pipe forms a flange, the breadth of which is the interval E G and I F between two concentric circles; on this a leather roundle, N K L, is fitted, hollowed from N to L to admit the tail of the valve, whose diameter is less than G I, and greater than the hole H, in order that it may close it more exactly. The figure shows that when the flanges are fitted together, the tail of the valve N and the leather roundle, O Q P, will be between them, which are fastened together by nuts and screws. The iron or copper plate R with which the valve is loaded, that it may close more quickly, is also circular, and its diameter should be rather greater than that of the hole H, especially in forcing-pumps, that the pressure which it must sustain may not bend it.

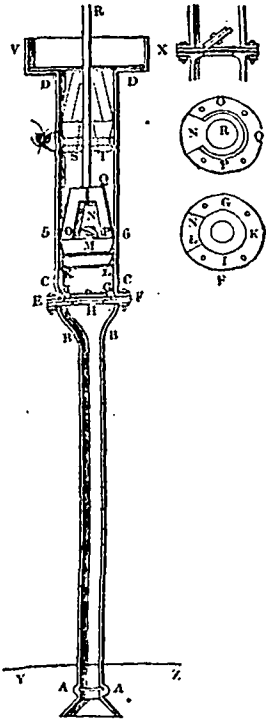


Fig. 1771. SUCTION PUMP.

When the piston is raised, a vacuum is produced in the space I S T G, or the air is more highly rarefied, and that in the suction pipe being no longer in equilibrio with that in the pump-barrel, forces open the valve G, which closes the communication between the two pipes, expands in the space I S T G, and becomes equally rarefied from the surface of the water to the base S T of the piston. The weight of the atmospheric air then pressing on the surface of the water, Y Z, forces it into the suction pipe to a certain height, and having reduced the air contained there to its natural density occupies its place. Thus the water will ascend more rapidly at first, because as it drives forward the air, it condenses it, and becomes its own obstacle to further progress: for example, if it stop at 3 feet above the water, and the weight of the atmosphere is equivalent to a column of water 31 feet high, the elasticity of the air remaining in the pump is capable of sustaining a column of water 28 feet high, after the condensation caused by the water which has ascended.

If the piston be lowered, the valve G will close, the air contained in the space I S T G, being more and more compressed as the piston descends, acquiring an elasticity superior to the atmospheric pressure, and will raise the valve N, and escape by the hole K L M. If the piston be again raised, the valve N will close, and the air in the pipe A B, dilating in the space I T, the atmospheric weight will raise the water higher than at first; continuing to work the piston, the water will rise in the pump-barrel to a certain height, 5 6, and the space I S T G will be filled partly by water and partly by air, which will be compressed into the space 5 S T 6. On lowering the piston, the valve C will close; the air remaining in the pump-barrel will be forced through the piston with a part of the water, which having once risen above the valve N, there will be no more air below, and the water will accompany it to the height S T: on lowering the piston, the water will pass above it, and when it is again raised will run into the cistern V X; thus the whole play of the pump consists in the action of the external air, and the play of the two valves N and G, which open and shut alternately.

Forcing Pumps have the same parts as suction pumps, but are differently placed, as shown in the figure: the pump-barrel A B C D dips in the water to be raised, and is united to an ascending pipe, E C H F, by flanges and screws; this pipe is composed of two pieces, the first, C H E F, is bent in such a manner as to offer no obstacle to the motion of the frame T X Y V, which carries the rod N of the piston M; and the second E G H F, the diameter of which is uniform, conducts the water to the height required. The piston of this pump differs a little from the suction, being pierced with a hole L, covered by a valve K, which opens from above downwards, its rod N O being attached to the cross piece R S and T V of the frame, which is suspended to a piece, Z, attached to a crank or lever. The barrel is sometimes in two pieces, to allow the water to ascend more freely: the upper part is pierced with a hole covered with a valve I.

The piston being at the base of the pump-barrel, it will leave a vacuum or highly rarefied air, arising from that between the valves I and K when first lowered. The water will then be pressed upwards by collateral columns, aided by the atmospheric pressure; the valve K will open; the water will pass through the piston, mount in the pump-barrel, and compress the air remaining there, which will be reduced to its natural state; but as soon as the piston remounts, the valve K will close, and the water above being driven upwards, will

open the valve I, and pass with the air in the pump-barrel into the ascending pipe: the piston then descending, the weight of the water in the upper pipe will close; the upper valve and the vacuum formed in the pump-barrel will be successively filled with water as the piston descends, which it will the more freely do, as it meets with no obstacle but the weight of the valve K, which is very small. When the piston re-ascends, the water supported by it will again pass into the ascending pipe, and the pumping being continued, will arrive at the height required.

The Suction and Forcing Pump, fig. 1773., consists of a barrel, A B C D, a suction pipe, C D F E, and a branch G K N O made in three pieces; the first, G K, is cast with the pump-barrel, the second, I K M L, forms the elbow, and the third, L N O M, conducts the water to the reservoir. At the junction I K is a clack valve, S, opening and shutting alternately with the valve R, at the bottom of the pump-barrel; the first, S, retains the water in the ascending branch, to prevent it from descending at the time of suction.

The piston P Q V T is solid, and traversed by an iron rod attached by two keys; it consists of two equal truncated cones united at their summits; each cone has a slightly cup-shaped band of leather.

As the piston must not descend lower than T V, because it would otherwise close the mouth G H of the ascending branch, there will necessarily be condensed air in the space X T Z, which cannot be prevented, although an essential defect. When the piston is first raised, this air dilates in the pump-barrel and ceases to be in equilibrio with that in the suction pipe, which forces open the valve R to expand also, and allows the water to ascend some feet. The valve S remains closed, and is with difficulty opened, because the air in the ascending branch, by which it is pressed, has more elasticity than that on the side of Z. But when the piston descends, the valve R closes; the air contained in the pump-barrel being pressed acquires an elasticity superior to that which presses the valve S, which it opens, and the air in the pump-barrel passes into the ascending branch, as long as they are in equilibrio. On raising the piston t valve S closes; the other, R, opens; the air in the suction-pipe again dilates, and forced up the ascending branch. Continuing to pump, the water reaches the barrel, where it mixes with the air that could not be expelled, which is forced with part of the water by the descent of the piston into the ascending branch: that below passing without difficulty into the pump barrel, whence it accompanies the piston upwards, and the same action is repeated.

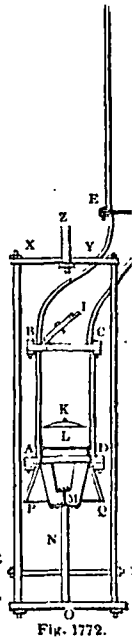


Fig. 1772.
FORCE-PUMP.

Pumps of this kind may be variously constructed, and different positions given to the suction and ascending pipes, relatively to the pump barrel.

Fig. 1774. shows the suction pipe C D E, separated from the barrel to which it is united above, in order that the piston, which differs in no respect from the preceding, except that the rod is carried by a frame, may force the water from below upwards, while the other forces it from above downwards. It is evident that, when first lowered, it will form a vacuum in which the natural air enclosed in the space C B will dilate; that in the ascending branch will then open the valve C, and expand in the pump-barrel. On raising the piston the valve F will open, and the greater part of the air will be driven up the ascending branch G: by continuing

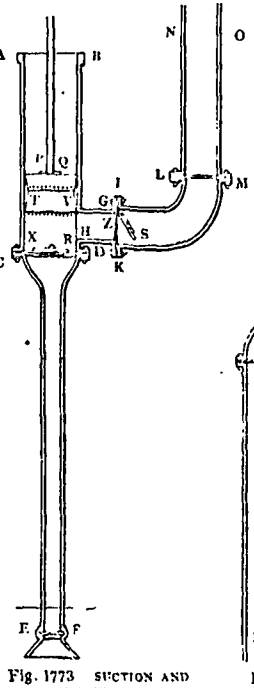


Fig. 1773 SUCTION AND FORCING PUMP.

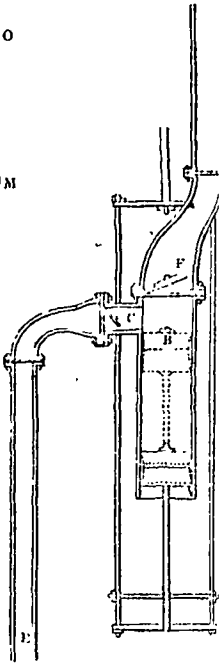


Fig. 1774 SUCTION AND FORCING PUMP.

to pump, the water will rise to the barrel and ascend in the pipe G.

The pumps of the third kind have sometimes two pistons, one of which sucks while the other forces the water; those of Notre Dame at Paris were of this description (fig. 1776.); they consisted of a frame, C D, attached to the rods M and N, which when raised, the water from the river passed into the suction pipe, E F, by the pressure of the external air, and raising the valve Y mounted in the barrel A B, which the piston I left void; when the frame descended, the valve X opened, the other Y closed, and all the water from the pump-barrel, passing through the piston, discharged itself into the cistern H G. On the other hand, the piston O descending left a vacuum in the pump barrel P Q; the air which pressed on the surface H W of the water in the cistern raised the valve T, and the barrel was filled: on the piston ascending, the valve T closed, forced the water to open the other, V, and passed into the pipe R S, which closed as soon as the piston descended. Thus the cistern always remained full, the piston I sucking as much as the other forced; the diameter of the lower barrel should be rather more than that of the upper, in order that there may always be more water in the cistern than can be raised, in order to supply the loss sustained.

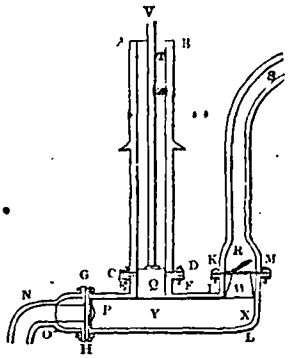


Fig. 1775. PUMP USED AT MARLY.

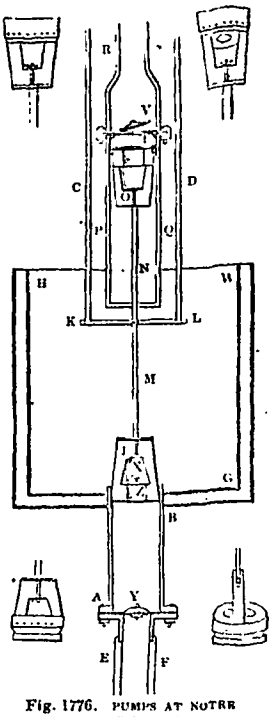


Fig. 1776. PUMPS AT NOTRE DAME BRIDGE.

Fig. 1775. is another pump of the same kind belonging to the Machine of Marly. It has a communication pipe, H L M K I F D C E G, in one piece, one end of which, G H, is joined to the suction pipe N O, which dips in the water, the other, L M K, bent at a right angle, unites with the branch K S M, which conducts the water to the first reservoir. In the middle is a branch E C D F joined to the pump-barrel A B C D, in which the piston Q works, perfectly cylindrical and solid, traversed by a rod Y V, suspended as will be hereafter described. When the piston ascends to I, the air in the part P X dilates in the space Y Z; that in the suction pipe N O opens the valve P, mixes with the preceding, and the valve R remains closed by the atmospheric weight: but when the piston is lowered, the valve P closes, the other R opens, and the air is forced in the pipe S: when, after a certain number of strokes, the water arrives in the barrel, it is forced into the ascending branch S.

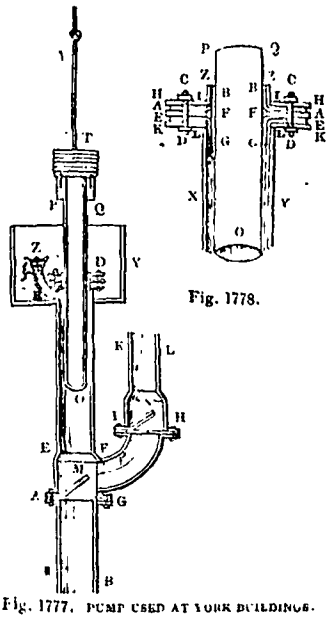


Fig. 1778.

Fig. 1777. B is a suction and forcing-pump once used at York Buildings, on the Thames. The suction pipe A B is united to the barrel C E F D, having a valve M at the junction; the ascending branch F G L K has also a valve N to close the aperture I H of the bent part G I. The piston O P Q is a hollow cylinder of copper filled with lead to give it sufficient weight to force the water into the branch; and as the height of the water might be so great that the weight of the piston would not effect this, it is also loaded with plates of lead, T, placed on the rod V; the head of the piston, therefore, which does not enter the pump-barrel, has a square form, sufficiently large to serve as a base to the weight T.

Fig. 1777. PUMP USED AT YORK BUILDINGS.

To avoid the friction of the piston against the inner surface of the pump-barrel, which would be considerable if it operated on its whole length, its diameter is a little less than that of the pump-barrel, so as to leave a small interval between them: to prevent the communication with the external air, which would be an obstacle to suction, and that the water when forced may not issue through the mouth of the barrel C D (fig. 1778.), a very simple and ingenious contrivance is used. The entrance L L of the barrel is provided with a flange K L, which surrounds and is cast with it; on this are applied two or three roundles of leather E F G, bent round the inner surface of the barrel, and then a copper ring whose lesser diameter is a mean between that of the pump-barrel and that of the piston. Upon this other roundles are placed, A B Z, bent like the preceding, but in an opposite direction, the whole covered by a second copper ring, H H, whose lesser diameter, I I, is equal to that of the barrel. This ring is united to the flange K L by screws, CD, fitted with nuts; thus the middle ring serves as a guide to the piston, which only touches the leather Z G, with which it is intimately united, for as there is always water in the cistern X Y (fig. 1777), the leather is continually swelled. This water, not being able to escape, prevents the external air from entering the pump-barrel, and when necessary the leathers may be removed, and the pump repaired without taking it to pieces. In order that the water from the pump may keep the cistern always full, a small cock R is added, which communicates with the barrel and is closed by a key S: when the piston plunges, the water mounts in the cock, and by turning the key S is admitted into the cistern; as the violence with which it is pressed by the piston would make it rush out impetuously, a plate of copper, Z, is opposed to it, supported on four branches. This cock also serves at the first moment to expel the air from the barrel quicker than if it were driven out through the branch, it being opened and shut alternately at each stroke of the piston. In all these pumps, the water only ascends the branch at intervals, that is to say, when the piston plunges, consequently the time of suction is lost. Large pumping machines, as that of the Samaritaine at Paris, therefore have always at least two separate barrels, A, B, fig. 1779., uniting in the same branch C by the pipes D and E, so that when the piston F sucks, the other G forces, and the water continually ascends. In this manner, the pumps of the Samaritaine, at Paris, were constructed.

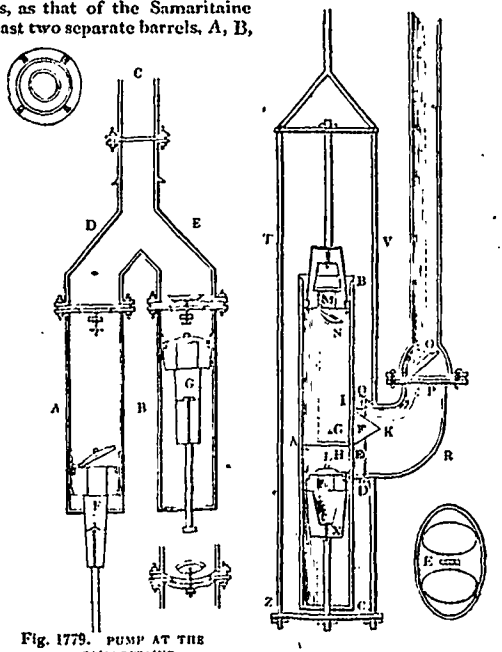


Fig. 1779. PUMP AT THE SAMARITAINE.

Fig. 1780. shows a pump having a pipe C A B divided into two equal parts A B and A C, forming two barrels uniting in the same branch Q D R, with which they communicate by two holes G and H. At this end the branch is elliptic, as well as the two holes G and H, which open and shut alternately by means of a valve common to both; below is shown the valve in face, and sideways, with a section through the middle; this valve is entirely of copper, either solid or hollow, provided it be strong, and it shows that it works on a hinge at E, between the holes G and H, which is its centre of motion.

The frame Z carries two pistons, working in opposite directions; for if we suppose the machine plunged in water to the height T V, it will be seen that when the frame ascends, the valve N of the piston M opens, and the water enters the first barrel A B; that in the second, A C, being forced by the piston X passes through the hole H into the ascending branch, supports the valve F in the situation represented, and while it slides along the face E K, the other E I leans against the orifice G, which it keeps shut. But as soon as the frame descends, the valve N closes, the other L opens, and that in the middle changes position; the water in the pump-barrel A B passes through the hole G, to be forced in its turn up the ascending branch, and the hole H is closed by the face E K. On the other

Fig. 1780.

hand more water enters the barrel A C, occupying the vacuum left by the piston, to be forced in its turn as before; it will thus alternately pass through the holes G and H, and ascend without interruption into the reservoir: as it continually passes through the hole P, the valve O is not necessary, but is convenient; for if the play of one piston should be interrupted, the other would raise the water, as in ordinary forcing-pumps.

Fig. 1781. raises water continuously, but in a more simple manner than the preceding: the pump-barrel D B is united to a recipient X Y Z, of a cylindrical figure, covered by a half sphere Y; these two pieces communicate by a hole G, opening and shutting with a copper clack valve H: the suction pipe A D joins the pump-barrel, and the ascending branch Z W the recipient; both have their valves F and V as usual; the piston C is solid, and worked by a frame.

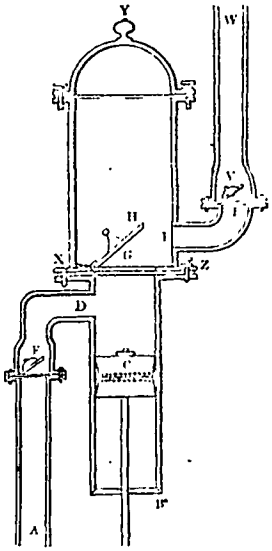


Fig. 1781. CONTINUOUS STREAM.

When, after several strokes of the piston, the water rises in the suction pipe above the valve F, it passes thence into the barrel, and is forced upwards; it then enters the recipient, and reaches nearly the same level in the branch I T above the hole I; the air in the recipient not being able to escape, and the piston continuing to suck and force more water, a part rushes into the branch and part remains in the recipient, which increases the elasticity of the air, as it is compressed to a less space; the hole G, by which the water enters, being greater than I, by which it escapes, the piston always forces more than can at the same time ascend the branch: as the valve H closes every time the piston descends, when the air in the recipient acquires an elasticity superior to the weight of a column of water having for its base the circle of the recipient, and for its height that of the ascending branch, the air would exert a pressure on the surface of the water, and oblige it to descend; and the diameter of the recipient being much greater than that of the ascending branch, if the water descended only a few inches, it would furnish enough to pass into the reservoir during the time of suction. It would in this manner ascend without interruption, since the piston, at each stroke, drives twice as much water as can in the same time escape through the hole I.

In order that the air may always have the proper elasticity, and not acquire more than necessary, it is convenient to have a small tube in the recipient, fitted with a valve, which, being loaded with a weight proportioned to the elasticity of the air, maintains the equilibrium.

Hedderwick's Double-Piston Pump differs from those which have rods attached to one side of the pistons, and which produces an unequal pull upon them: this inconvenience is remedied here, by attaching the piston-rod to the centre of the piston, the lower passing through the centre of the upper.

When the long handle of this pump is depressed, and the other raised, the two pistons follow the same motion; which being reciprocal, gives a double advantage in lifting the water; for, when the one handle is pulled down, the piston attached to that handle is raised; and when the same handle is raised up, the other piston is also raised, which belongs to the opposite handle: such a contrivance would raise twice as much water in the same time as two others with pump-barrels of equal bore with one piston each. It has been proved that a pump with two pistons will actually raise twice and a half as much water as another pump with one piston only. It must be recollected also, that in the pump with a single piston the water, after being put in motion, is suddenly stopped, during the descent of the

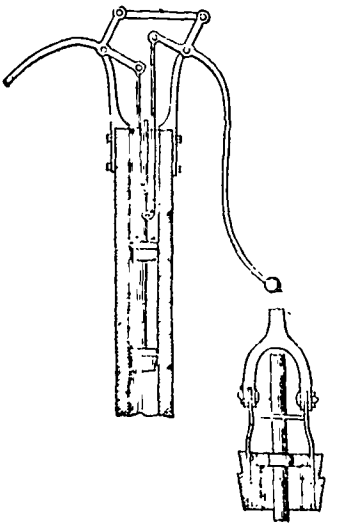


Fig. 1782. HEDDERWICK'S DOUBLE-PISTON PUMP.

piston, and consequently the discharge of water through the pipe is not regular, whilst the pump with two pistons causes it to flow in a continual stream: that part of the rod of the lower piston is shown at the side of the figure.

In Taylor's Sucking Pump, the piston rods have racks at their upper parts, working on the opposite sides of a pinion, and are kept to their proper position by friction rollers: a pump of this description, with a bore of 7 inches, will lift a ton of water 24 feet high in a minute, when worked by ten men, five on each side. There are three kinds of valves employed; the first is a spheric segment, which slides up and down on the piston-rod, and is carried down by its own weight; the second is a pendulum valve; and the other a globe which is raised by the rising water, and falls again by its own weight.

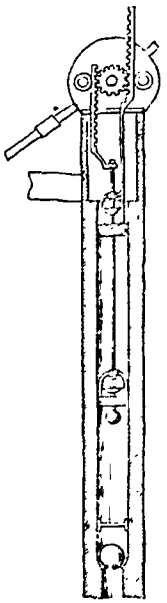


Fig. 1783. TAYLOR'S PUMP.

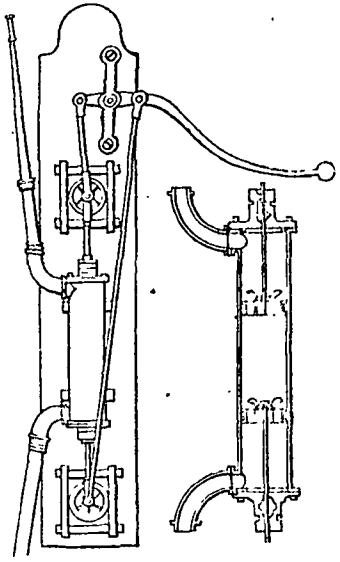


Fig. 1784. FRANKLIN'S DOUBLE-PISTON.

Franklin's Double-Piston Pump, with a section through the cylinder. When the handle or lever is raised, the upper piston pressed down, the lower piston elevated, and its valves shut, the water is forced through the upper piston and the discharging pipe. When the handle is pressed down, the upper piston rises with its valves closed, and the water in its ascent is forced through the discharging pipe: at the same time, the lower piston descends, by which action the valves are opened, and a fresh supply of water is obtained: with a 6-inch stroke, a quantity of water equal to twelve inches of the cylinder is discharged: whatever the length of stroke, the quantity of water supplied is doubled.

Stephen's Forcing Pump. — To the handle is attached a wooden rod of several lengths, united by iron joints, and capped with iron forks firmly riveted. The bucket works a brass tube, and the top of the barrel is covered with a metal lid, which has a stuffing-box in the centre, to receive the metal cylindrical part of the pump-rod, to the lower extremity of which the bucket is fixed. The metal lid consists of a ring screwed to a wooden barrel by five screw bolts. The forcing pipe may be made of wood, or from crooked timber.

The ordinary forcing-pump does not furnish an intermitting stream of water, but this effect is very simply attained by the addition of an air-vessel, fitted upon the side of the main or rising pipe of the forcing-pump. The action of these air-vessels may be thus explained: suppose the pump to have received water above the valve, a part of which will get into the vessel and compress the air within it, with a force proportional to the height of the column in the main pipe; when, by the next stroke, the piston draws up more water, and it stands higher in the main, the air-vessel is more powerfully compressed. After the water is lifted to the point at which it is discharged, the air in the vessel becomes so much compressed, that it balances the whole height of the column above it. If the opening through which the water flows at the top of the main were sufficiently large to permit the water to issue with the same velocity as that of the piston, it would flow

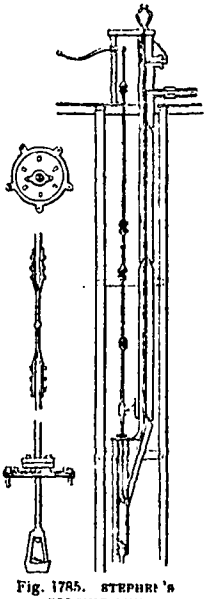


Fig. 1785. STEPHEN'S FORCING-PUMP.

over, rising no higher by each successive stroke, and occasioning no additional compression of the air in the vessel. But if the aperture of the main is diminished to half its size, the whole of the water cannot pass during the stroke; consequently a portion goes into the air-vessel, and increases the compression of the air included within it.

Trevithick's Pressure Engine resembles one mentioned by Belidor, although it may be considered more perfect in its arrangement.

Chain Pumps.— As every ship of war is provided with a number of chain and hand pumps, great attention has been paid to their construction. Mr. Cole was the first to rectify their numerous defects, adding a contrivance by which the chain could be easily taken up and repaired. The old chain pumps required seven men to raise a ton of water in seventy-six seconds, and Mr. Cole was enabled to do the same work in forty-three seconds.

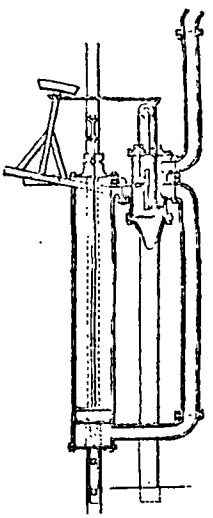


Fig. 1786. TREVITHICK'S PRESSURE-ENGINE.

Mr. Smeaton contrived a hand-pump for the use of ships, calculated to remedy the defect of delivering the water on the main deck, which was the ordinary custom; thus lifting the water considerably higher than was necessary: to obviate this, he introduced horizontal wooden pipes to carry off the water through the ship's sides, at as low a level as possible: one end of these pipes proceeded from the upright trunk of the pump, and the other was fitted into boxes, or short wooden tubes, let in through the ship's side, and caulked above the low water line; these side pipes were closely jointed with the boxes in the ship's sides at one end, and at the other end into strong planks, which were bolted against the sides of the pump, in order that the side pipes might be got out and in without disturbing the pump, which was a sucking-pump with its bucket worked by a lever upon the deck, over it. From the top of the pump a stand-pipe was carried up to the main deck, or as high as was thought necessary to prevent the water running back into the ship, over the top, when the sea rose above the orifice of the side pipe. The pump had three handles, which four men worked at a time; they effected 25 strokes per minute, and moved the pump-rod 17½ inches up and down each stroke.

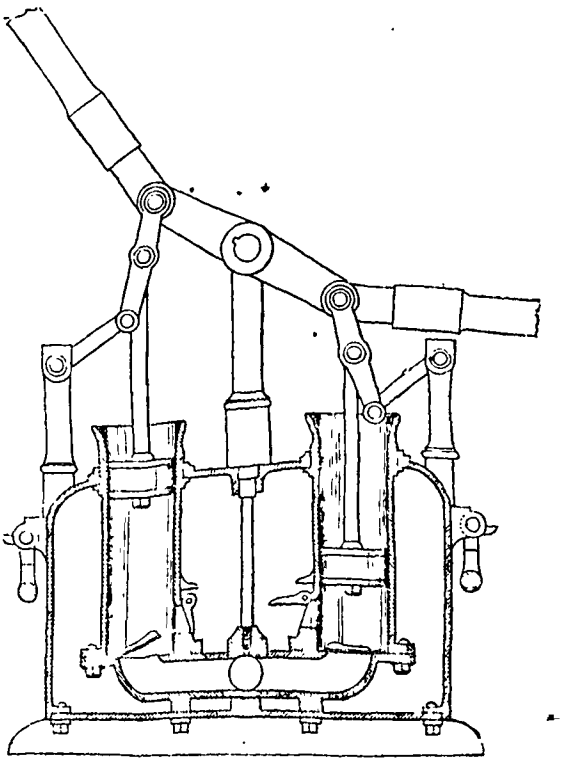


Fig. 1787. KINGSTON'S SHIP-PUMP.

Kingston's Ship Pump consists of 2 brass cylinders, 4 inches in diameter, at the bottom of which is a pipe communicating with each. The space around and between the cylinders and the casing of the pump serves as an air-chamber, by which the water is kept under compression. The supply of water is through a hose, screwed on to the lower pipe, and the action of the solid piston is the same as that of the force-pump: water is thrown out by this pump in a continued stream through the eduction pipe when used for ordinary pumping, or through a flexible hose when it is employed to extinguish fire.

The Chain Pump for Ships is formed of a long chain, with a number of pistons or buckets fixed upon it at regular distances, and which pass over two wheels called *sproket* wheels; by turning the upper one, the buckets are put in motion, and working in a wooden tube lined with brass, as they mount they raise the water on the ascending side, which flows off by a trough placed over the ship's side. The links of the chain are formed of two iron plates, and the buckets or saucers are two circular brass plates with a piece of leather between them.

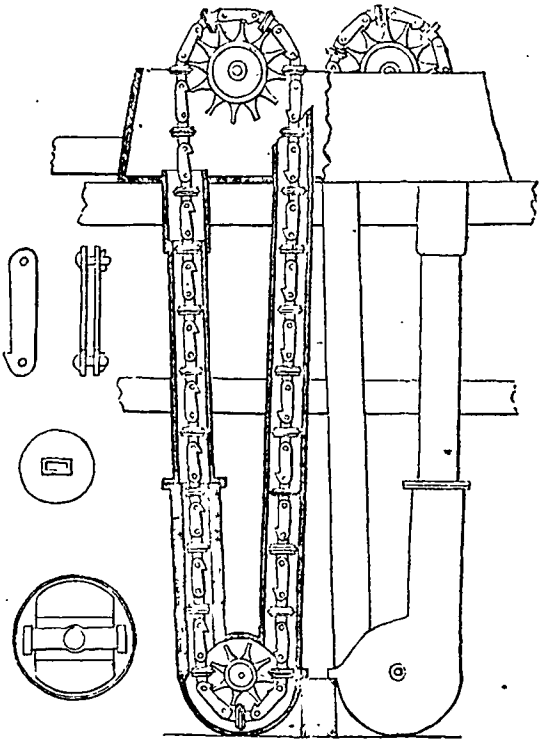


Fig. 1788. CHAIN PUMP, USED IN THE NAVY.

Double-acting Fire Engine is worked by a double sector of iron, which has a sufficient breadth of sole to receive two chains, similar to those used in a clock: one chain is fastened to the bottom of the arched head and to the top of the piston-rod, and the other chain is fixed at one end of the top of the arched head and the lower part of the piston-rod, so that when the sector descends on one side, the chain fixed at its lowest part winds round, and pulls down the piston on that side, while in the opposite sector the chain fixed on the upper part of its arched head winds round and raises the other piston: the reverse takes place at the next stroke, so that a continued action is maintained, the water rushing at the same time through the lower valve, from the cistern, and fills the cylinder; and when the piston descends, this valve shuts by the pressure of the water, and is forced through another valve into the air-vessel, the upper part of which is filled with air compressed by thus forcing the water in, and which, acting by its elasticity on the surface, causes the water to be thrown up with considerable velocity. An iron handle is attached to the air-vessel, which sets the cock into a position either to make a communication between the cistern and barrels, or between the feeding pipe and barrels, shutting off the cistern, according as the engine is supplied.

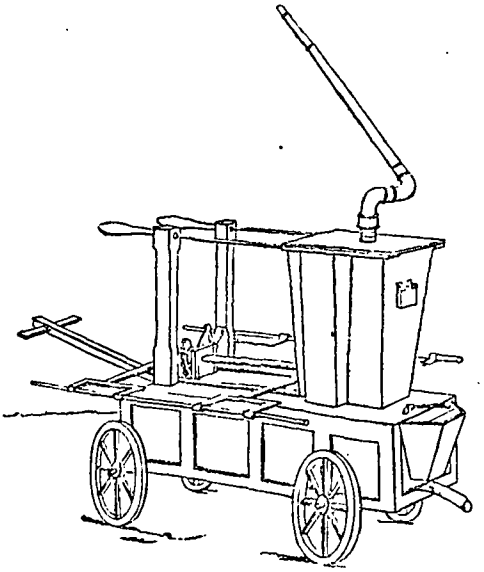


Fig. 1789. DOUBLE-ACTING FIRE ENGINE.

Let us suppose the air compressed in the air-vessel to half its

bulk by forcing in the water; if an additional quantity be thrown up, so as to compress this half to one-third its original bulk, there will be the pressure of three atmospheres internally to one externally, which will support a column of water 66 feet high.

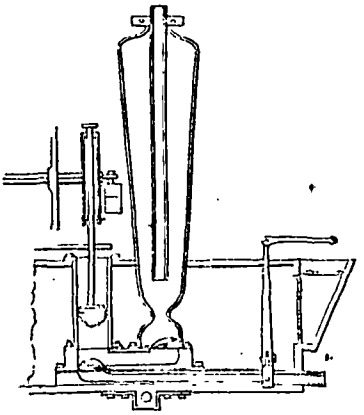


Fig. 1790. AIR-VESSEL.

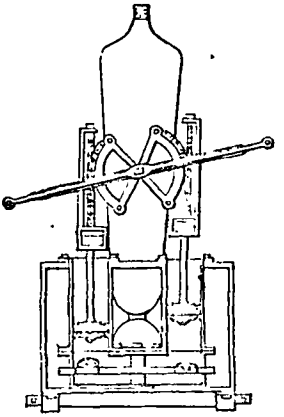


Fig. 1791. SECTION OF FIRE-ENGINE.

Attached to the water-mains in many towns is a fire-plug of ingenious contrivance, which, when the water is supplied from a high service, answers all the purposes of an engine, and can be made available at a moment's notice.

The fire-engine now preferred has two cylinders of 7 inches in diameter, and a stroke of 8 inches: the whole weight of such an engine, when strongly made and rendered efficient for use, is about 17½ cwt., without taking into consideration that of the hose and tools required, which may make an addition of 4 or 5 cwt.; this, however, can be easily drawn by two horses with five firemen and a driver any short distance. There are two pumps, both sucking and forcing, the pistons of which are moved up and down by a double lever: when one piston is up, the water flows from the reservoir into the barrel, and when the same piston is depressed, a valve shuts, and the water of the barrel is forced into an air-vessel into which is inserted a pipe which reaches nearly to the bottom of the vessel. The same effect is produced by the other piston, only at a different moment, for when one is rising and sucking water from the reservoir, the other is forcing into the air-vessel the water which it had raised into the barrel by its previous ascent: when the water has risen in the air-vessel to a certain height, the air becomes more and more compressed by every new quantity of water forced into it, until the elasticity of the air, acting like a spring on the surface of the water, compels it to mount the hose which is attached to the engine. The usual rate of working such an engine is 40 strokes of each cylinder per minute, which gives 88 gallons, and it requires 26 men to keep it at work steadily for 3 or 4 hours. The lever is in the proportion of 4½ to 1, and with 40 feet of leather hose and a ⅞ inch jet, the pressure is 30 pounds on the square inch: this gives 10·4 pounds for each man to move 226 feet per minute. The friction must be added, which is equivalent to 2½ per cent. for every additional 40 feet of hose.

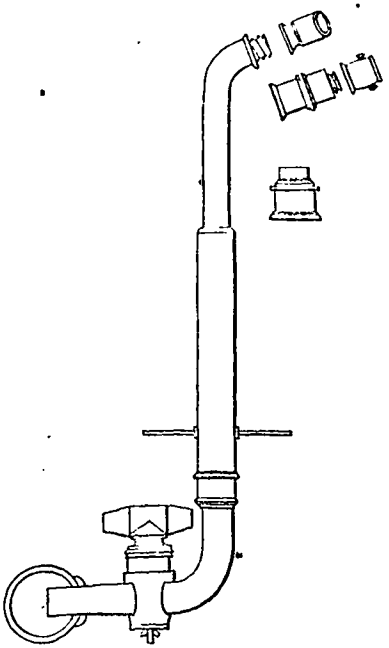


Fig. 1792. FIRE-PLUG.

A variety of forms are adopted for the jet, but that generally used has the curve of

the nozzle determined by its own size: $\frac{1}{10}$ of the difference between the jet to be made and the end of the branch is set upon each side the diameter of the upper end of the branch; a straight line is then drawn across, and an arc of a circle described on it, from the extremity of each end of the diameter of the jet, until it meets the top of the branch: the jet is then continued parallel, the length of its own diameter; the metal is carried $\frac{1}{8}$ of an inch above this, which allows a hollow to be turned on its edge.

The size of the jet on the inside is proportioned by making its diameter $\frac{1}{8}$ of an inch for every inch in the diameter of the cylinder, for each 8-inch stroke: when the water is to be carried to a greater height, a jet whose area is $\frac{1}{4}$ less is made use of, with a branch from 4 to 5 feet in length. The following table will show how the water acts upon the surface of the water in the air-vessel.

Height of Water in the Air-vessel.	Height of the compressed Air.	Ratio of the Air's Elasticity.	Height to which the Water will spout.	Height of Water in the Air-vessel.	Height of the compressed Air.	Ratio of the Air's Elasticity.	Height to which the Water will spout.
$\frac{1}{1}$	$\frac{1}{2}$	2	33	$\frac{7}{8}$	$\frac{1}{8}$	8	231
$\frac{2}{2}$	$\frac{1}{3}$	3	66	$\frac{8}{8}$	$\frac{1}{9}$	9	269
$\frac{3}{3}$	$\frac{1}{4}$	4	99	$\frac{9}{10}$	$\frac{1}{10}$	10	297
$\frac{4}{4}$	$\frac{1}{5}$	5	132	$\frac{n-1}{n}$	$\frac{x}{n}$	n	$(a-1)\,33$
$\frac{5}{5}$	$\frac{1}{6}$	6	165				
$\frac{6}{6}$	$\frac{1}{7}$	7	198				

The common Garden Engine is made in a variety of forms, and with pipes, pistons, air-chambers like that already described; in some the working barrel is placed on the outside, and in others the wooden case is dispensed with.

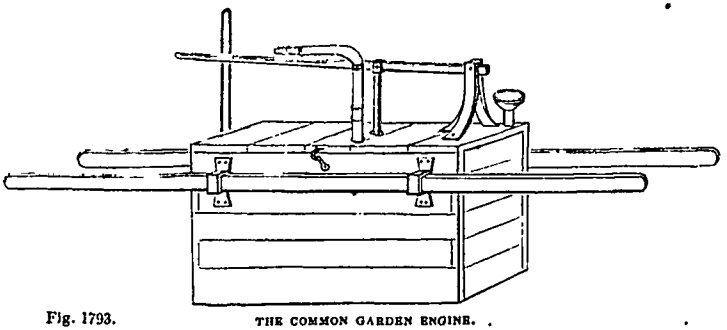


Fig. 1793. THE COMMON GARDEN ENGINE.

Another form of this engine will show the sort of pump sometimes adopted for throwing up water from one level to another: but among machines employed for such purposes, pumps are the most convenient, as they can be made readily to vary the height to which the water can be thrown, as well as to occupy the least space in the interior of a cofferdam: the body of such a pump is the prolongation of an air-tube, and the motion is usually communicated by men acting on a balance.

M. Boistard, who has recorded the useful effect of the pump, observes that one 27 centimetres in diameter, (10·6 inches English) worked by seven men for eight hours, raised 508·52 cube metres of water 3·628 metres in height; the useful product daily attained

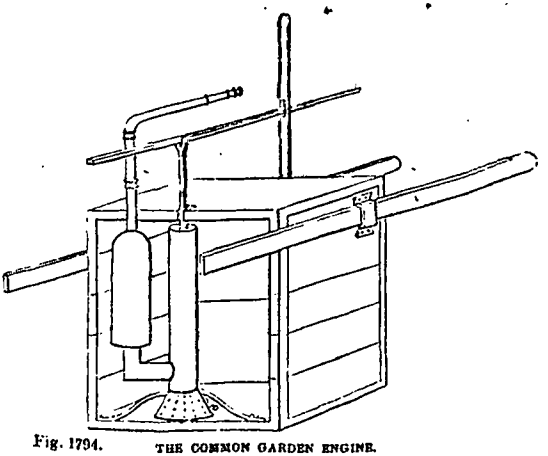


Fig. 1794. THE COMMON GARDEN ENGINE.

is for each man 87·85 cube metres of water raised 1 metre: another pump 244 millimetres, (or 96 inches English,) worked by the same number of men for the same time, raised 470·04 cube metres of water 3·573 metres in height, which gives for the useful effect furnished by each man in 24 hours 79·97 cube metres of water raised a metre. The product of pumps varies much in consequence of the manner in which the piston is connected with the air-tube, but they are now brought to great perfection by the manufacturer, and it is found that those of the greatest diameter are the most economical for raising water from foundations.

Engine for raising Water from Dykes is contrived like a fire-engine with a double handle, working two pistons in barrels attached to an upright pipe: after the water is thrown up in the trough above, it can be poured out in any direction required; the mechanism and barrels resemble some of those already treated on.

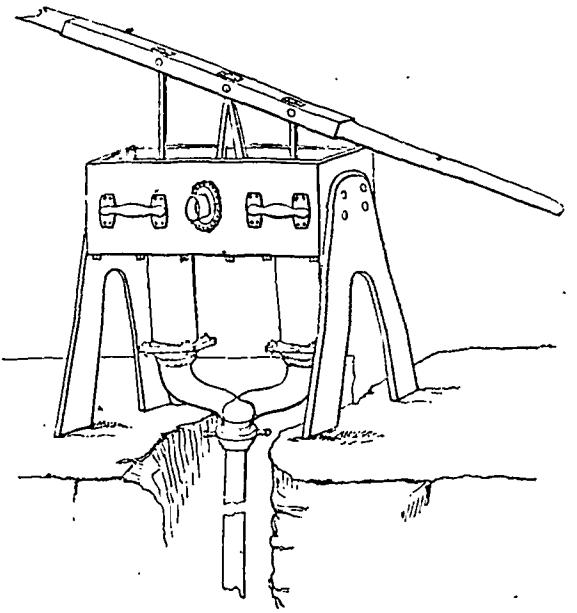


Fig. 1795. ENGINE FOR RAISING WATER FROM DYKES.

Pistons and Valves. —The pistons in general use are of two kinds, solid or plungers, and pierced or buckets; both are commonly of wood: the chief inconvenience of wooden pistons is that when pierced with holes they are greatly weakened, especially if sufficiently large to allow the water a free passage, without which there is considerable resistance; and if a stroke of 6 feet be made in two seconds, as in the machine at Frene near Condé, it is essential that the whole machinery should work with the most perfect ease, otherwise the effort of the moving power tends to the destruction of the machine. To avoid this, care must be taken that when the bucket descends, its own weight should suffice to compel the water at the bottom of the barrel to pass through the hole in the time necessary for its descent; and as this time is determined by the velocity of the machine relatively to that of the moving power, it will be seen that it depends on the quantity of water sucked by the bucket at each stroke, and the size of the passage to be traversed.

Suppose, fig. 1776., a pump-barrel, A B, 8 inches in diameter inside; that the stroke of the piston is 6 feet, and that it is made in two seconds; it will raise at each stroke about 74 pints of water, which should pass through the hole Z in the time of the piston's descent, with what weight ought it to be loaded in order to force the water, so that it may in two seconds pass through the hole, which we suppose 3 inches in diameter, the greatest which can be given to it without weakening the bucket too much? The quantity of water which will pass through the piston in a given time will depend on the size of the hole and the velocity communicated to it by the weight with which it will be loaded: the problem is therefore to ascertain what height of water must be given to a reservoir pierced at the bottom by a hole 3 inches in diameter, so that 74 pints may issue in two seconds.

If the piston weighed less than the column of water, the hole must be increased to make up for the small velocity of the water arising from a want of sufficient pressure and the superficies of the two holes, and the velocity of the water which must pass must form four terms reciprocally proportional. But as the weight spoken of may be expressed by columns of water whose base is the circle of the piston, and the square roots of the height of these columns expresses the velocity of the water, we may substitute the square roots of the weight with which the piston is loaded without fear of error.

As wooden pistons are not very convenient, since we cannot pierce them with a hole of sufficient size without endangering their solidity, one of the description of the fig. repre-

sented will be found infinitely preferable: it consists of a copper box forming the body of the piston, in the form of a truncated cone, with a small flange, C C. The figs. 1799. 1802.

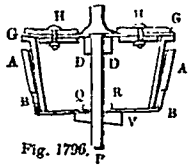


Fig. 1796.

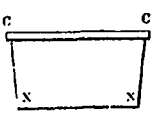


Fig. 1797.

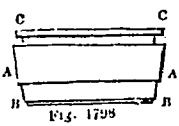


Fig. 1798

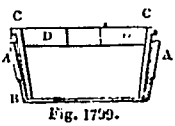


Fig. 1799.

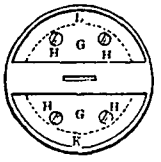


Fig. 1800.

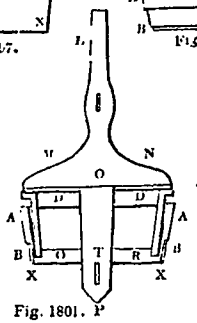


Fig. 1801.

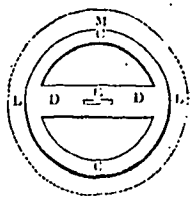


Fig. 1802.

show the section with the upper plan, where it is seen that this box is traversed by a bar D D pierced by a mortice E: on the surface of the box is a leather band A A, confined by an iron ring let into the leather, which is $\frac{3}{12}$ of an inch thick.

The piston is covered by a leather valve strengthened by iron or copper plates G, G, (fig. 1800.), made in the segment of a circle: above the valve are similar plates, but of rather less diameter, so that they may enter the piston, as indicated by the circle I K in fig. 1803., having only therein the leather and upper plates, which rest on the edge of the box; thus the leather is screwed between the two by four nuts and screws, H: this valve is fitted to the box, so that the centre F F is placed on the bar D D; to tie the whole together an iron cross is used, L M N O P, in fig. 1801., which is a section through the bar D D of fig. 1796. The part M N is placed, on the middle F F of the valve; then the tenon O P traverses the hole E, and passes through an iron bar Q R, whose extremities, X, X, are halved into the thickness of the box, as well as the circle B B, which is sustained by this means, and secured to the box by passing a key into the hole T, as shown in the section of the piston at right angles with the preceding.

The rod L O is adjusted to an iron bar by a tenon at its summit, a mortice in the middle, and two screws serving to tighten one against the other; this bar is suspended to a crank or lever.

To remedy defects in the common plungers of wood, a much more solid one is now substituted, as shown in fig. 1803. The body of the piston consists of two copper cylinders A B C D, E F G H, of a screw N O, and a ring Z, all cast together; the diameter C D is rather less than the barrel Q R S T, and the diameter E F only half the preceding; the thickness A C may be one-fourth the diameter A B, and E G twice E F.

A number of leather roundles, whose diameter is rather more than the pump-barrel, pierced in their centre by an aperture of the diameter G H, are fitted on the cylinder E F G H, and beaten with a hammer to press them together; others are then added, supported by a copperplate I K, the thickness of which should be half A C, and being pierced in the centre is fitted to the screw L M, after which the whole is pressed together by the nut X. The piston is then placed on a lathe to reduce the whole to the same diameter as the piston head, and form a cylinder I A B K, having a uniform surface. The piston is then introduced into the pump-barrel without difficulty, and water being poured above the leather it swells, and all the roundles unite against the barrel, and form a new cylinder Y, whose diameter is equal to that of the barrel, leaving no admission for air during suction, nor passage for the water when forcing: in proportion as the surface of the cylinder Y wears by friction, the leather swells, not having attained its maximum of dilatation in the first instance, especially if it be of the best quality.

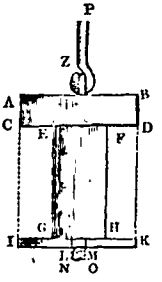


Fig. 1803.

PLUNGER.

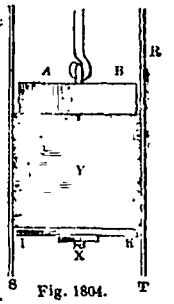


Fig. 1804.

The ring Z serves to hook on the rod P, so that it may play freely, and enable the piston

in ascending and descending to work perpendicularly: it being impossible to make the rod do this at all times, especially when worked by a crank, great freedom of action must be allowed in forcing-pumps; therefore it is better to hook it to the piston than to attach it.

Although the preceding piston is one of the best, it must be acknowledged that after a certain time, when the leather has successively swelled to compensate for the decrease caused by friction, the adhesion will not be sufficient to prevent the passage of water when forced, if the column be very high, for the resistance caused by its weight will always be the same, while the adhesion of the piston will continue to diminish. To remedy this there must be a power proportioning its adhesion to the pressure exerted in forcing; this has been effected by a copper cylinder *g h*, hollow and pierced with several holes covered above by a plate *a b* of the same material, both cast together with the flange I K, serving to attach the cylinder to a second plate *c d*, similar to the first, with this difference, that it has a hole of a diameter equal to the interior of the cylinder, to which a cup valve is fitted, in such a manner that the tail is retained between the flange I K and the plate, the whole being secured with nuts and screws: on the edge of each plate is a groove to receive the hem of a leather purse of a cylindrical shape, for which the plates serve as ends. Pitched twine is used to unite them, well tightened round the leather, forming a drum, and having only an opening at the bottom when the valve at K is raised; the piston is attached to the rod H, having three or four branches I G, united to the plate *a b* by nuts and screws. Water being poured into the pump-barrel until it is three-fourths full, the piston is introduced, which will enter without difficulty; but when it descends lower the air contained beneath, being compressed, will raise the valve, pass into the cylinder *g h*, thence into the drum, and, continuing to descend, the water will pass also, until the piston arrives at the hole N O; the air and the water then swelling the drum, the leather will begin to adhere to the pump-barrel, feebly it is true, but sufficiently to prevent the introduction of the external air when the piston is raised, the valve instantly closing.

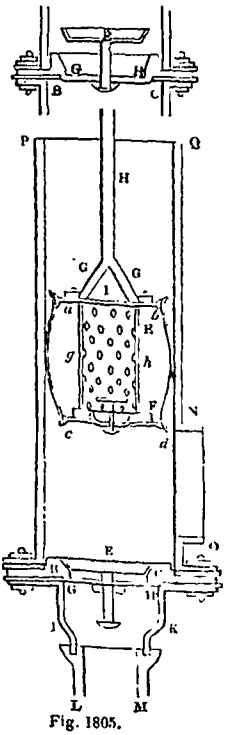


Fig. 1805.

As the piston works and expels the air from the suction-pipe, the water will rise in it, and enter the barrel: when arrived there, the piston forcing it will itself receive a part, which will compress the air at each stroke into a still less volume, and the action of the piston becoming stronger as the water is raised to a greater height in the branch, the air in the drum will acquire still more elasticity, and press the leather more and more against the barrel, the water therein acting in the same manner as the air. When the branch is full, the elasticity of the air will be in equilibrio with the column of water, of whatever height it may be, and whether the piston forces or sucks its adhesion will always be the same: when the barrel is not sufficiently cylindrical, this defect, which would be very great in any other case, will be of no account in this, since the surface of the piston being flexible will adapt itself to whatever opposes it.

The piston just described cannot lose water, its surface being perfectly applied to the barrel; but as from this adhesion great friction results, the leather will not last long: it is therefore necessary, in order to avoid its constant renewal, to place several, one over the other, to strengthen the purse, which will not be the less flexible, but adapt itself to the barrel; the friction in this case being very different from that occasioned by the contact of two hard bodies, it is highly desirable to get rid of friction entirely, but in doing so, care must be taken that other inconveniences are not produced, which may overbalance the one advantage.

Messrs. Gosset and De la Deuille, while engaged on a very ingenious hydraulic machine, invented a piston entirely free from friction, which may be used independently of the machine: the piston may be of any size, even 3 feet in diameter; that described is 15 inches: the barrel consists of two wooden plates 28 inches in diameter, and 5 thick; in the middle of each is a cylindrical hole 15 inches in diameter and 2½ deep, forming two boxes placed against each other; their section is represented by the rectangles A B C D and E F H G. The piston consists of a circular plate, Y L, 1 inch thick, the diameter of which ought to be rather less than the void T O Q V, to facilitate the play: this plate is applied to a large circle of leather, or to several, if one is not sufficiently strong, so as to project 6 or 7 inches all round the edge; the plate is placed in the bottom of the box S T V X, and the excess is folded all round the edge E S X G; the other box, A B C D, is then applied to the preceding,

and the leather fixed between them by means of several iron bolts fitted with screws: thus the piston consists of a kind of purse, which turns itself at every stroke of the piston. At the bottom of this purse is a hole, L, covered with a valve, K, which, when raised, rests against the handle M W M, to which a rod, N, is attached, serving to raise and lower the piston; for this rod there is another hole in the bottom of the upper box, corresponding with the pipe in which the rod N passes; this hole is slished, to allow the plate to touch the top O Q when the piston ascends; the lower box has also a hole corresponding with the suction pipe, covered by a valve, I, as usual: when the piston is raised the water opens the valve I, and passes into the vacuum formed to the height of 4 inches, which is the play the piston ought to have so as not to weaken the leather: when the piston descends the valve I closes, the other, K, opens, and the water contained between the bottom, T V, and the leather, passes through the hole L, enters the space O P Y Z Q, and thence is forced up the ascending pipe; thus the piston, always floating between two waters, will have no friction: when the leather is good, it may be worked continually for three or four months without any repair, as has been proved in the mines of Bretagne.

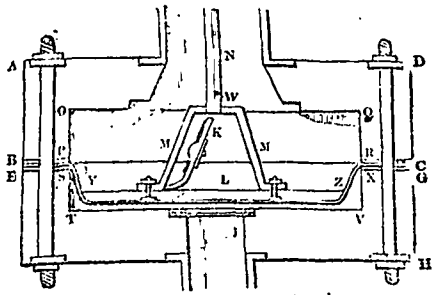


Fig. 1806. GOSSET AND DE LA DEUILLE'S HYDRAULIC MACHINE.

The sole defect in this piston is, that, whatever be the size of the discharge-pipe, the power is always loaded with the weight of a column of water having for its base the circle O Q, and for its height the elevation of the reservoir above its source: it is true the diameter of the pipe may be increased, and that of the piston diminished, in order that these being equal, the power may not be loaded with a greater weight than would naturally be raised: the play of the piston being small, it will raise but little water at each stroke; the strokes may, however, be more frequent. If the suction-pipe and the piston-rod are each 25 feet long, the water may be raised 50 feet above the source at a very small expense.

On Valves. — The different valves in use may be classed under four kinds, the cup valve, conical valve, spherical valve, and clack valve; the three first are of copper.

Fig. 1805. shows a cup valve E, at the bottom of a pump-barrel; the stalk, accompanied by two leather roundles, is fixed between the flanges of the barrel and those of a cup I K, to which the suction-pipe, L M, made of lead, is soldered: the valve E fits the cup B C, G H represents the support of the ring in which the rod F plays.

The upper fig. 1805. represents a section of the same valve, in order to show its defects, which are decidedly great: the superficies of the great circle E diminishes the passage of the water, as it can only escape through the space between the circumference of the circle B C and the surface of the suction-pipe, whereas the water forced by the piston should have a free passage equal to the circle of the barrel, in order that it may not pass more rapidly into one part than another; otherwise the power will be forced to make a greater effort than if the water were not confined.

To give more facility to the water in ascending, it is only necessary to diminish the circle E; but this cannot be done without also diminishing its lower surface, or its equal G H, consequently, without confining the passage of the water through the cup B C: all that can be done is to regulate the upper and lower diameter of E, so that the water, in traversing the cup and passing round the valve, should be as little confined as possible; therefore the superficies of the circle G H must be equal to the ring causing the difference between the superficies of the upper and lower surfaces of E. Of whatever size the barrel is, to proportion the valve, we must divide the radius of the barrel into five equal parts, and take three for that of the small circle of E, and four for that of the great circle: due consideration having been given to the height which best suits the convex surface of the valve, it appears that its side should be one-fourth the diameter of the upper circle, and the breadth of the rest one-eighth; the angle which it makes with the side will then be of 60°, because the section of the valve will form a trapezium drawn by an equilateral triangle, having the upper diameter for its base.

The water forced from the barrel up the branch will be greatly confined in traversing a very narrow passage; it will in its course meet the under part of the cup, and the circle N D which causes it to rebound, and it will only be raised by an extraordinary force, besides which it will be pressed in a direction obliquely to the surface of the pipe. The power must be twelve times greater than if the water mounted with a uniform velocity. This valve is not applicable to forcing-pumps, if placed at the bottom of the branch, but may be used at the bottom of the barrel: for if the greatest height of the

piston be 27 or 28 feet, the atmospheric weight will be sufficient to raise the water in the barrel with a velocity much greater than the piston can have.

This valve sometimes fits the cup so tightly that it ceases to play: M. Amontons having constructed a forcing-pump, dipping 6 feet in water, was surprised on observing that the valves of cast-iron, and perfectly fitted, suddenly ceased to act; he several times took the pump to pieces, but could not discover any sufficient cause for the defect. The valves were placed horizontally in the barrel, and had they been pressed by the atmospheric weight, they might have been imagined in the condition of two well-polished surfaces, which can only be separated by a very great weight, but there being no air between the valves and piston, they were only pressed from below upwards by the water which the piston forced.

The only one cause to which the union of the valve and cup can be attached is their being maintained by the water, whose particles attract each other so forcibly as to exclude the air between them, and so require a great effort to detach them, which can only be effected by evaporation or violent friction.

The conical valve, fig. 1807., consists of a truncated cone E resting in a cup B C, similar to the preceding, except that it has no ring in the middle, the stalk being very short: at its extremity is a plate R G, which prevents the valve from escaping; its great circle should correspond with a convex head, whose edges should have sufficient projection to close the aperture when the valve is down; for there being nothing to keep the axis of the cone in the centre, it may, by moving right or left, leave a space through which the water in the branch may escape into the barrel. This valve has the same disadvantages as the other, that of contracting the passage of the water.

The spherical valve, fig. 1808., is much more simple, consisting only of a sphere E, which falls into a cup B C when the piston sucks, and would certainly be superior to any other if it did not contract the water-way, for, once placed at the base of the pipe, it would play a number of years without needing any reparation: it is true the branch may be enlarged above and below the valve, so that the whole of the cup, and the passage of the water around the sphere, may be equal to the circle of the piston, and the water have a uniform velocity, which would render this valve infinitely more perfect. Care must be taken not to make it too light or too heavy; if too light, and the branch is of the same calibre with

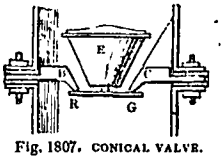


Fig. 1807. CONICAL VALVE.

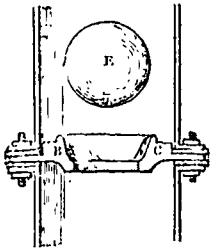


Fig. 1808. SPHERICAL VALVE.

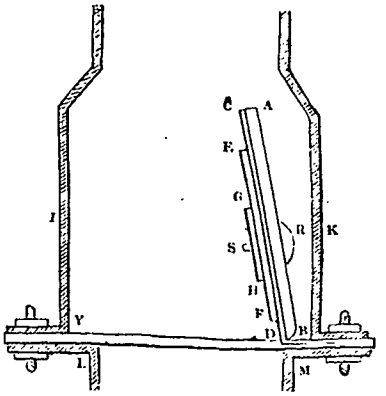


Fig. 1809. CLACK VALVE.

the barrel, the impulse of the water would raise it to a great height, and the valve would not close soon enough to prevent the water coming back: it might even happen that the same water would pass continually from the barrel to the branch, and back again as the piston forced or sucked, for if the passage be not closed at the moment the impulse ceases, no fresh water will rise in the barrel nor in the reservoir: if, on the contrary, the valve be too heavy, the power will have to raise it as well as the water. To obtain the proper mean the specific weight of the valve must be regulated by the velocity of the piston, that it may never go further from its cup than just sufficient to allow the water to pass, unless it be retained by a chain.

The clack valve, fig. 1809., is the least imperfect, leaving a free passage for the water: the valve A D consists of a piece of leather, C D, tightened between two copper plates, A B and E F. The diameter of the first is two or three inches greater than that of the pipe L M: that of the second E F is rather less, in order to enter within it: these two plates are held together by a screw S R and nut G H; the leather has a tail, D B, serving as a hinge, as

usual. This valve, placed at the bottom of the branch, is lodged in a drum I K, so as not to contract the passage of the water at that place; the lower part of the branch is swelled, in order to have a ring, Y, all round the flange of the pipe L M for the valve to rest upon, which is consequently horizontal, a situation preferable to the vertical, which do not close well; it is true the void space is not so great.

This valve must be made strong, otherwise the leather hinge will soon be injured; being the weakest part, these kind of valves always give there, especially when much strained, and being liable to frequent reparations are consequently not convenient for large pipes, as in falling they often slip more on one side than another and do not close exactly; the leather of the hinge becoming too flexible has not sufficient body to keep the valve in its proper direction. To remedy this inconvenience, when the branch is 8 or 10 inches diameter, a valve may be formed of two clacks, consisting of a ring of copper, as in the first piston described, whose lesser diameter is equal to that of the ascending-pipe, and its greater sufficient to admit of being held between the flanges of the drum and those of the curved pipe. This ring should have a bar, D, so as to make one piece of the whole, as shown in section in fig. 1811., where L M represents this ring with the bar A: a leather circle, 2 inches more in diameter than the ascending branch, will form the two clappers, E, I, strengthened above and below by copper plates G, H. The circle of leather is laid on the cross piece, A; a copper rule of the same length is then placed above it, and they are united by two screws, as in fig. 1810., where the rule B C has a knob D E to prevent the two claps both falling on the same side. This valve is the most convenient, and contracts the water-way so little as not to be of any importance.

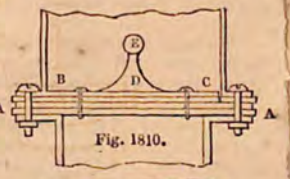


Fig. 1810.

Fig. 1811.

Leather clappers not being very durable, those of copper are substituted in two semicircles, united by a hinge, as in figs. 1812, 1813, 1814, 1815. The lower, on the right hand, represents them when closed; they are fitted in a box B B, projecting equally with them, and moving on two hinges, G, G, whose axis enters the two uprights E: on the top of each is a button F, to maintain the clappers in the situation shown by the two upper figures, and oblige each to fall towards its own side, when the piston ceases to force. The tongue A A should be formed with roundles of leather between the flanges, I K and L M.

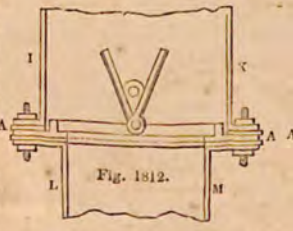


Fig. 1812.

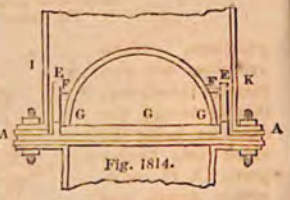


Fig. 1814.

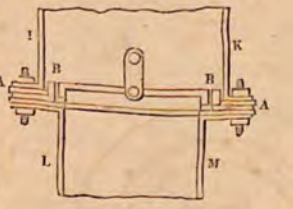


Fig. 1813.

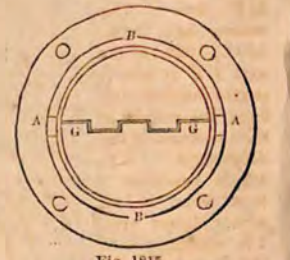


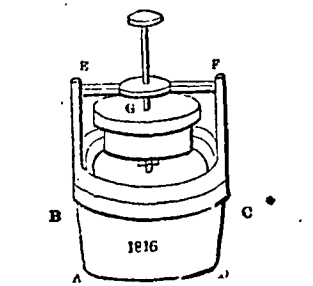
Fig. 1815.

In selecting the best form for valves, we must always consider the purpose to which they are to be applied; the most important considerations are, that it should be perfectly tight; that it have sufficient strength to resist the forces to which it is exposed; that it allow the water to pass freely, and not permit it again to flow back, whilst it is in the act of closing. The clack valve, which is the simplest, should be fixed in a box like a piston; its outer surface should be a little conical, so as to fit a similar recess made for it in the tube; it should have an iron ring or handle to enable it to be taken out by a hook whenever it is required to be drawn up: the top which the clack valve sustains, when opened, may be considered as equal to one-half of the cylinder of water, whose height is equal to the diameter of the valve. The spherical valve obstructs too much the passage of the water, and when made very light there is the probability that it will not return to its place when required, without allowing a quantity of water to flow back.

Another valve placed at the bottom of reservoirs or basins for the purpose of laying them by or filling them, fig. 1816.; it consists of a copper box A B C D, having a rebate B C

hollowed out, to admit the cover G, to which a rod H is attached for opening and shutting the valve, working up and down through the cross bar E F.

Fig. 1818. is a pump used by Belidor to replace the old one in a machine at the Pont Notre Dame, Paris; its chief advantage is in the valves, which offer less resistance to the passage of the water; the valve, fig. 1820., consists of a circular diaphragm movable on



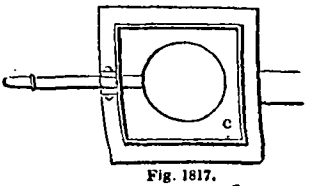


Fig. 1817.

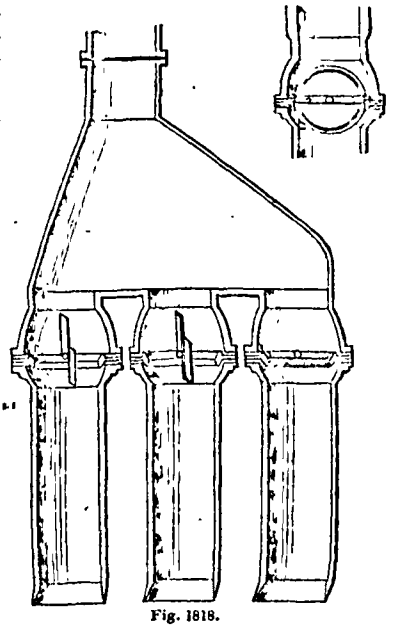
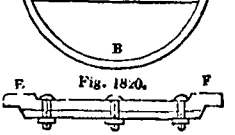


Fig. 1818.

gudgeons, whose axis does not pass through the centre; that is to say, the diameter being divided into twelve parts, A H comprises seven, and H B five. The centre, figs. 1825., 1821., 1822., of the axis E F is also $\frac{1}{12}$ part of the diameter, from the middle of the thickness of the diaphragm A B, which produces a bent lever K I H, whose lesser arm, I K, corresponds to the friction of the gudgeons, and the other I H sustains at its extremity H the weight of the valve, which can only remain open when obliged by some superior force. The unequal segments of which this valve is composed

Fig. 1819.



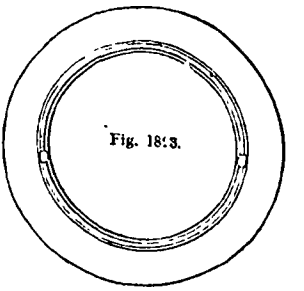


Fig. 1823.

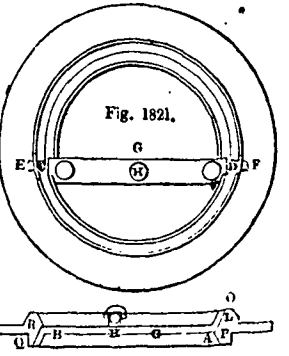


Fig. 1822.

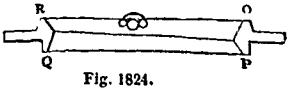


Fig. 1824.

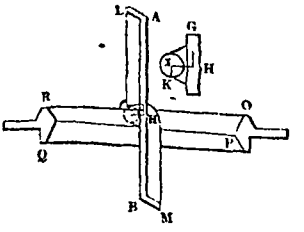


Fig 1825.

are cut, fig. 1825., A L, B M, in opposite directions, so that when it is closed the first, A L, which belongs to the greater segment, pressing downwards on the upper

edge O P of its frame, and the other, B M, upwards against Q R: when the piston forces, the water presses the valve upwards, but with greater force, against the segment H A, fig. 1822., than against H B: the valve then assumes a vertical position, and the water passes freely on each side the valve. On the other hand, the instant the piston begins to descend, the valve ceasing to be supported by the ascending column, closes by its own weight, and the column above pressing with much greater force on the segment H A than on H B, it is impossible that it can open: in order to give greater superficies to the inner circle of the ring or plug than to the piston, the summit of each pump-barrel is enlarged to make way for the valve when open, and not to oppose any obstacle to the water; on which account the fork of the old pumps was suppressed, and their place supplied by a large receiver, as in fig. 1818., cast with the barrels; thus the water forced by the pumps unites in the receiver, and passes in a mass up the branch.

Manner of setting out the head of the Pump-barrel. — Divide the diameter A B into eight equal parts or modules; on the centre raise the perpendicular C D three modules high; through the point D draw the line H G parallel to the diameter A B, and from the point D as a centre, with the radius D A or D B, describe the arcs A E and B F. The rebates E H and F G must be one module wider than the thickness of the pump-barrel: to trace the profile of the head, draw the rectangle I Z L K, whose base I K is eleven modules, and whose height I Z is two; on the line I K draw another rectangle M T X N, whose base M N is equal to the diameter A B of the pump-barrel, and whose height M T is six modules. Divide the line Z L into three equal parts, as at Q R, and from these points as a centre describe the ares Z T and L X; prolong the perpendiculars M T, N X two and a half modules to the height T V, X Y.

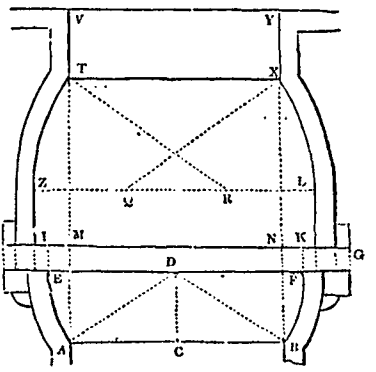


Fig. 1826.

Figs. 1827. 1828. 1829. represent the piston of this pump: its construction is based upon four principles; first, that it should have an aperture sufficiently large to allow water enough to pass to fill the barrel at each stroke; secondly, that the valve in the piston should open and allow the water to pass freely, and yet itself close firmly; thirdly, that the axis of the piston should always be vertical, notwithstanding the obliquity given to the rod by the motion of the crank or balance beams, so as to avoid any straining, and to prevent the pistons wearing on one side more than on another; fourthly, that the leather which causes the adhesion of the piston to the inner surface of the barrel should be so disposed as to last a long time without requiring reparation.

This piston consists of a cast-iron box, I C D K, figs. 1827. 1828. 1829., serving as a nucleus to a number of leather rings, G, H, pressed against one another, having a flange E F for their base: at the summit D is a screw furnished with a nut, A B, to bring the leather rings together. To the piston a swing valve is attached, similar to that previously described. The base of the box has two ears, I, K, traversed by a bolt, L M, which secures them to the fork of the piston-rod.

The suction piston is entirely on the same principle as the preceding, figs. 1830. 1831. 1833., only the flange A B must be at the upper part as well as the ears C, D, which attach the piston to the rod. The ring of the valve is let into a rebate, and attached to the flange with four screws.

The various methods of raising water by means of pumps may all be classed under three heads. The first, when water is raised from a depth to the surface of the earth, which may be performed by employing as many suction pumps as may be necessary. The second, when water is to be raised to a great height above the surface, either vertically or on an inclined plane; in this case forcing-pumps are employed. The third, when the water is to be raised from a depth

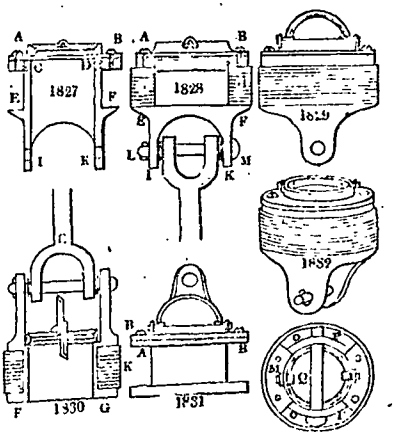


Fig. 1833.

considerably below, to a height considerably above the surface of the earth; this case comprising the two former, both suction and forcing-pumps must necessarily be employed.

Fig. 1834. represents a suction-pump adapted to raise water from a well or cistern: it consists of a leaden pipe 2 inches in diameter, dipping into the water, having its extremity curved and resting on a block of stone or wood. To this is fitted another leaden pipe, 5 inches in diameter, forming the pump-barrel; its lower extremity takes off to adapt itself to the suction pipe, and near their junction a wooden plug D is fixed, perforated by a circular aperture to which a clock or valve is fitted opening upwards, to prevent the descent of the column of water in the barrel. The piston is a similar plug, E, furnished with a valve, also opening upwards. To the upper part a band of leather is nailed, which fits the barrel rather tightly; the piston is attached to the rod by an iron stirrup. The power applied to the handle K works the bent lever M A I, whose arm L K is 30 inches, and L M 5; thus the power is $\frac{1}{6}$ of the weight, here expressed by that of a column of water 5 inches in diameter, and in height equal to that of the discharging pipe P above the level of the water. The tools F and G serve to draw up the lower valve, or to tighten it by striking it with the circular head of F. To draw it out, the valve O is first raised with the hook G, and the whole is then drawn up with the end H.

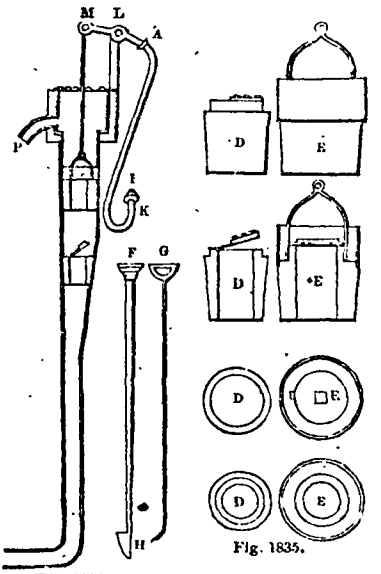


Fig. 1834. Fig. 1835.

Fig. 1836. is a pump with lever A working two piston rods, B, C, one of which is raised at the same time that the other is depressed, and may be used when the water is too low to be raised at a single stroke. For example, if a well were 40 feet deep, a pump might be placed at about half its depth, and another at the surface of the ground; the rod C would then raise the water to a height of 18 or 20 feet, whence it would be brought to the surface by B.

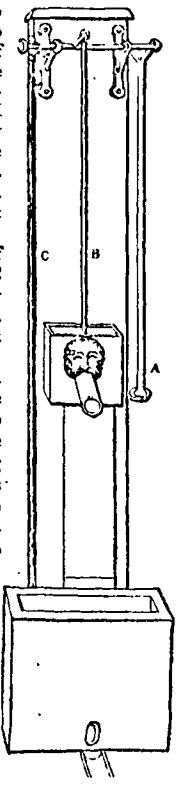


Fig. 1836.

Fig. 1837. is a suction pump worked by a balance E; the power is applied to a cord A, and raises the weight B, which by sinking raises the rod C. This pump is well adapted to serve two adjoining properties, by attaching a cord to the arm D of the balance, and passing it through the party wall, but one of the discharging pipes must be closed when the other is in use.

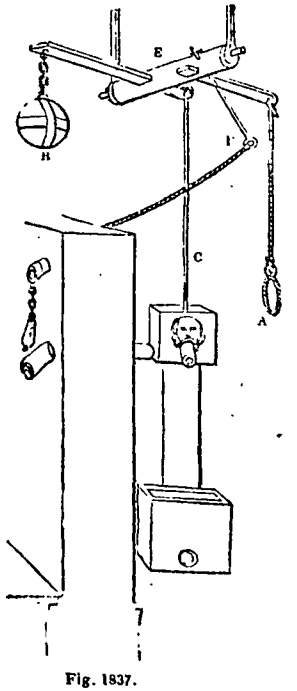


Fig. 1837.

Fig. 1838. shows a method of working two suction pumps alternately, so as to produce a continuous stream; the winch A, to which the

power is applied, has a fly-wheel B to produce uniformity of motion: on the axle is a pinion C, engaging a wheel D, whose axle is a crank G L M K I N O H, to which are suspended the piston rods E, F. The crank A is 12 inches long; M N is 6, and wheel D is 6 inches in radius, and the pinion C 2, and the fly-wheel B 3 feet. Supposing the water to be raised 28 feet by the power of a man, equal to 25 pounds applied to the winch A, it is required to find the diameter of the pistons in order that the weight of the column of water may be proportioned to the power applied.

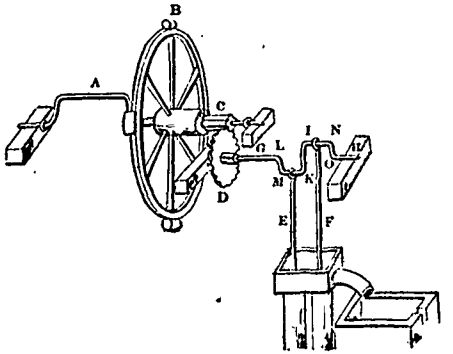


Fig. 1838.

This machine may be considered as consisting of a single pump barrel, whose piston raises the water in an uninterrupted stream, and the arm of the lever which corresponds to the weight as expressed by two-thirds of the arm L M or N O of the which. Now as there are four arms of one common lever united between the power and the weight, namely the arm L M reduced to 4 inches, the radius of the wheel D to 6, that of the pinion C to 2, and the arm of the winch A to 12; the power will be to the weight as 4×2 is to 6×12, or as 1 to 9, which may be stated thus, 1 : 9 :: 25 : 225 pounds, the weight of the column of water which the power has to raise, and the volume will be obtained by stating, as 70 pounds of water are to 728 cubic inches, so are 225 pounds to 5554 cubic inches, which must be divided by 28 feet, or 336 inches, the height of the column of water; we shall then have about $16\frac{1}{2}$ inches for the superficies of the circle of the base, or a diameter of $4\frac{6}{12}$ inches.

To calculate the Effect of this Machine. — The arm of the crank M N being 6 inches, the stroke of the piston will be 12; thus in each revolution of the crank, the two pistons will together discharge a column of water 2 feet high, $4\frac{8}{12}$ inches in diameter, weighing $15\frac{1}{2}$ pounds. The pinion C being one-third the radius of the wheel D, the power must make three turns of the winch A to one of the crank M N; and as this power can make 1000 turns in an hour, the crank M N will make 333, which multiplied by $15\frac{1}{2}$ gives 5161 pounds, or 184 inches of water per hour.

Fig. 1839. shows a very simple method for working two pumps by means of a balance beam, A B, loaded with a weight at each extremity; it works on gudgeons at C. Two foot-boards are attached to the beam at I, I; on these a man is placed who gives it motion: the whole is supported by four posts. At 10 inches from each side of the gudgeons the iron piston rods M, N are attached, which draw the water in the pump barrels O, P, and force it up the pipe L H to a height proportionate to the diameter of the piston and the action of the mover. It will be found useful to place an iron roller carried by steel springs, F, G, on each side, to assist the action of the balance beam: M. Morel, the inventor of this and several other machines, having remarked that where several men are required to ring large bells, a single person could put them in action by working a treadle, applied the same cella to working two pumps.

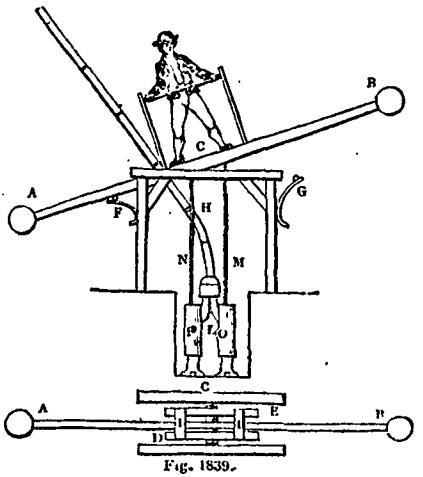


Fig. 1839.

Pumps with three barrels are sometimes used where the object is to keep up a continued current of water by the action of three pistons, one of which is at the bottom of its working barrel, while the second is in the middle, and the third at the top of each respective barrel. Mr. Smeaton made use of three pumps at the London Bridge water-works: when the pumps are small, the barrels are made of brass, and sometimes iron: opposite to the aperture of each barrel there is a short pipe, covered at the end by a door, through which a workman can get access to repair the valves, which are of iron, and which shut down upon hinges like a door, being covered with leather on the lower side.

Suppose A, fig. 1840., to be a weight of 200lbs. suspended to an axle traversed by an iron bar which carries two piston-rods. A man pressing with his foot on the treadle E would work both pistons, for when making an effort of only 60 pounds, the lever being 4 feet long, and the rods suspended to the centre of the axle, the weight may be four times the power; consequently, if we suppose the pistons 2 inches in diameter, they will force a column of water 154 feet in height.

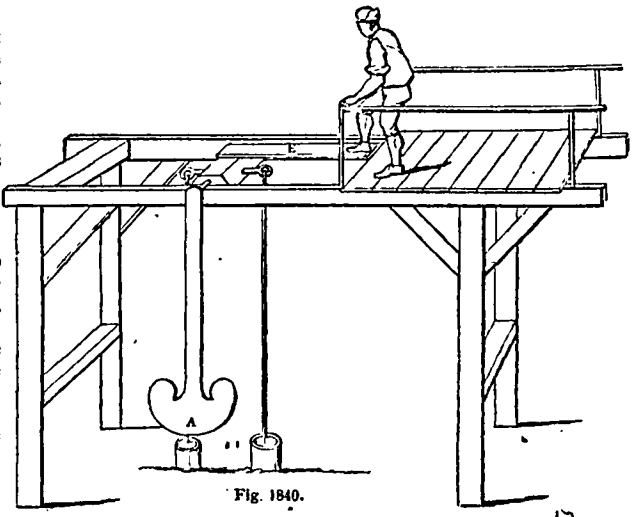


Fig. 1840.

Fig. 1841. represents suction and forcing pumps worked by one or two men at a winch A, on whose axle is a fly wheel and a pinion which engages two wheels C and D, to whose axles two lesser, E and F, are attached, having teeth on only half their circumference: when the winch is put in motion, it turns the pinion B, and consequently the wheels C and D; in like manner the two others E and F, which engage alternately in the racks G and H attached to the piston rods, one of which forces the water into the discharging pipe O, while the other raises it above the lower valve. The teeth of the small wheels being turned in opposite directions, the first E raises the rod G to the last tooth, after which the weight I causes it to descend, forcing the water to a height proportionate to the size of the pump-barrel and the weight of I, which should be greater than that of the column of water. On the other hand when G ascends and the piston sucks, the teeth of the other wheel, F, engage the rack H, making it descend to the last tooth; the piston N by the action of the moving power then forces the water up the pipe O; when the last tooth is past, the rod H is drawn up by the weight K, which must be rather above that of the column of water and the piston and rod. The two rods

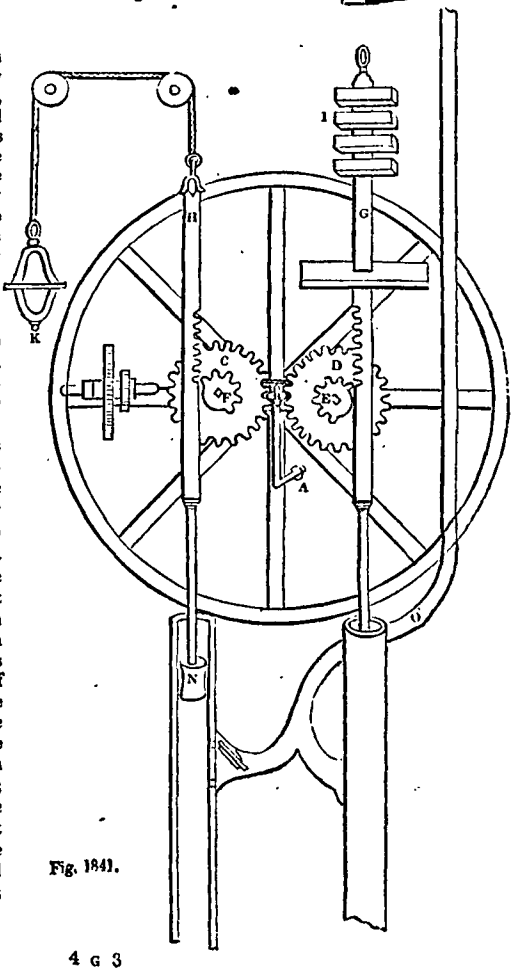


Fig. 1841.

G and H should work in guides to maintain their vertical position. The arm of the winch A should be 1 foot long, the fly-wheel 6 feet in diameter, the pinion B 4 inches, C and D 16 inches, E and F 4 inches in radius from the centre to the middle of the teeth. There being four levers between the power and the weight, viz. the arm of the winch 12 inches, the radius of the pinion 2, that of the wheels C and D 8, and E and F 4, the power will be to the weight as 2×4 to 12×8, or 1 to 12; consequently a man with a force of 25 pounds can raise a column of water of 300 pounds.

Fig. 1842. is a machine executed at Sources, a village of Alsace, on the road from Strasburg to Landau, placed over a large square well, the water of which is used for making salt. There are three floors, at 10 or 12 feet apart; the framework of carpentry, A, is placed on the first at the edge of the well, the cylinder B on the second, and the chest C on the lowest. A fall of water drives the wheel D, the axle of which, E, has 4 catches, X, Y, or wipers, which successively depress the levers F, G, and move the cylinder B by means of iron rods at the extremity of the balance K. Another balance, N, carries the piston rod, which is alternately elevated and depressed. The suction-pump H raises the water to the cistern C about 24 feet; the forcing and suction-pump I then drives it up the tube L 60 feet higher to the reservoir near the salt works. The dimensions for a similar machine will be nearly as follows:—the great water-wheel 5 feet in radius; the wipers X, Y 20 inches in length from the centre of their axle; the lever F V 5 feet 10 inches from its fulcrum to the point on which the wipers lean; the point T, to which the rod is attached giving motion to the balance K, is 5 distant from the fulcrum V, and the pistons each having a lift of 12 inches; the extremity of the wiper X must pass over a certain determinate length S F of the lever V F, in order that the point T, which has the same movement as the piston, may rise 12 inches and descend as much, whilst the wipers will act alternately on the levers F and G: if the wiper does not escape the lever F at the instant the piston reaches its lowest point, the machine ceasing to act may break some portion, for the wheel D continuing to turn will tend to surmount any obstacle which may prevent it. If, on the other hand, S F be too short, the wiper will not make the point T descend low enough,

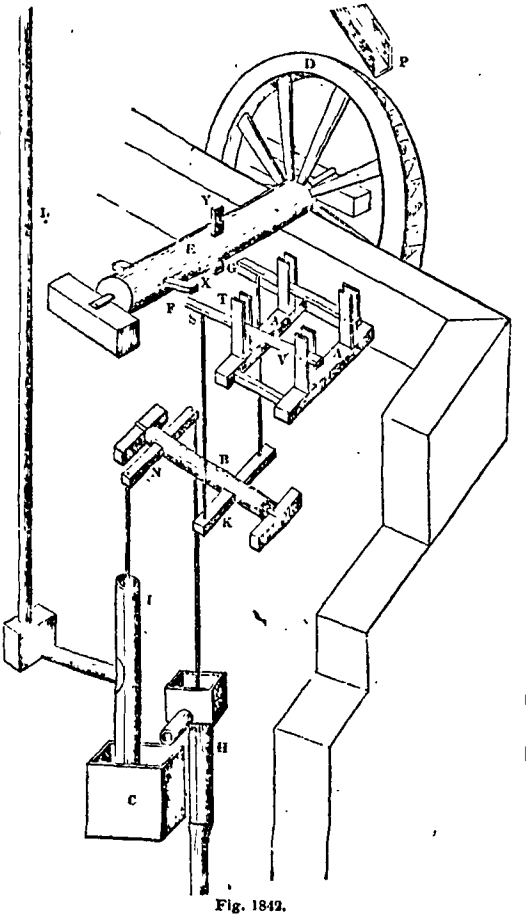


Fig. 1842.

and the piston not having a lift of 12 inches, the effect of this machine cannot be calculated on such data. The water-wheel must be considered as of 5 feet radius; the wiper X 20 inches in length, the power P will be to the effort made by the wiper on the point S as 1 to 3, and reduced to the point S may be expressed by $3p$, when the lever F V and the wiper X are in the same line: now, as the lever is of the second order, the power which will act on the point S will be to the effort which it will produce at the point T, to divide the rod downwards, as Y T to Y S, or as 6 to 7; the effort at the point T may then be expressed by $\frac{7}{6}p$. To find the diameter of the pump barrels,—since H sucks while I forces, they will together sustain the weight of a column of water 84 feet high. To find the base of this column in square inches, reduce $\frac{7}{6}p$ into cubic inches, by saying as 70

pounds is to 1728 inches, so is $\frac{7}{3}p$, to a fourth term, or $4\frac{32}{33}p$; this divided by 84 feet or 1008 inches, gives $\frac{3}{33}p$ for the superficies of the pistons, which multiplied by $\frac{11}{7}$ gives the square of the diameter, and being reduced gives $\frac{6}{33}p$, the root of which will be the required diameter. Supposing the force of the fall of water to be 110 pounds on each float-board of the wheel, substituting this number for p, we shall have 12 square inches, whose root gives $3\frac{23}{71}$ inches for the diameter of the pistons: although both the wipers X and Y are capable of exerting a force expressed by $3p$, those only which act on E V will exercise it entirely, since those levers alone suck and force the water; the other wipers Y only exercise a small portion of their force; the lever G not acting uniformly, the wheel turns more rapidly at one moment than at another. A second defect in this machine is caused by the wiper X not pressing equally on S F, because the direction in which it acts changes at every point of its course, as well as the length of the lever V S, which continually increases: to rectify this evil the wiper X, in place of being straight, should have the figure of an epicycloid.

Fig. 1843. is a more simple manner of arranging the same machine, invented by M. Morel. The wheel A is driven by a fall of water; its axle has two half wheels B, C, placed on the same side and about 3 feet apart, to work the pumps, which is performed by two racks attached to the piston rods, working in guides D, E: one of these is loaded with a weight F, to make the rod of the suction pump H descend. At the end of the other a cord is attached, passing over two pulleys, and carrying a weight G to raise the rod of the forcing-pump I; each rod has a stop to limit the stroke when it meets the guides. The wheel A, by driving the half wheel B, raises the piston rod D, and as soon as it escapes the rack, the weight F brings it down. On the other hand the weight G keeping the rod E at a proper height, when the half wheel C engages the rack of this rod, it drives it down and forces the water in the pump I up the discharging pipe K; the weight G then again raises the rod; thus the pistons suck and pump alternately. As the wheel B will only allow a small power to raise the water 24 feet high, and surmount the resistance of the weight F, plus that of the piston, whilst, on the contrary, the wheel C acts with much greater force on the rod E to overcome at the same time the resistance of the weight G and that of the column of water which the piston forces to the height of 60 feet, the wheel A will turn unequally.

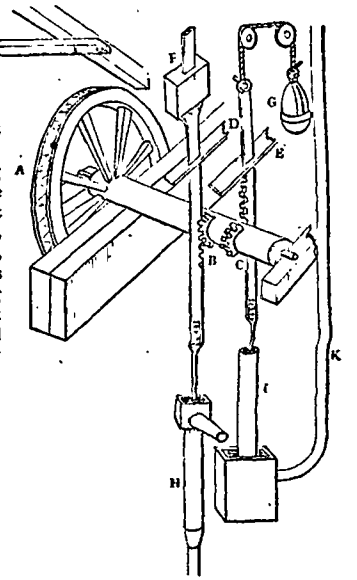


Fig. 1843.

Fig. 1844. is a machine executed at Nymphenbourg by Count Wahl, director of builders to the Elector of Bavaria, to raise water to a height of 60 feet, for the fountains in the gardens of the electorate. A stream turns a large wheel, which carries two cranks, working two

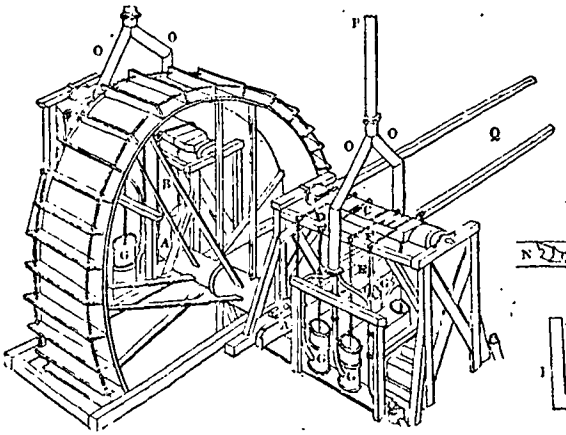


Fig. 1844.

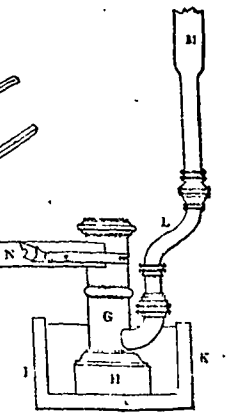


Fig. 1845.

NYMPHENBOURG MACHINE.

cylinders, C, by means of iron rods B, and these drive six piston rods, F, on each side the wheel; each system of pumps is contained in a trough, and firmly secured by screws to two joints pierced with holes to admit the water of the canal. The three branches of each system unite in the forks O, O which convey the water to the discharging pipe P; the pumps are tied together by interties, to which they are secured by iron bands; the depth of water near the fall at Q is 2 feet, and it has that velocity per second, as it runs along an inclined plane whose height is 10 feet: to find the absolute force of the current on the float-board, find a mean proportional between 2 and 12, which is 4 feet $10\frac{8}{12}$ inches, corresponding to the tabular velocity of 17 feet $1\frac{6}{12}$. Thus the absolute power may be regarded as equivalent to the weight of a column of water having the superficies of the floats for its base, and a height of 4 feet $10\frac{8}{12}$ inches; the diameter of the wheel is 24 feet, its float-boards are 5 feet long by 1 high; consequently the absolute power is equivalent to a weight of 1715 pounds.

The cranks are 1 foot in diameter, and so arranged that when one is horizontal the other is vertical: by this means the pistons of one only of the four systems force at the same time, by the action of a power which is only $\frac{1}{12}$ part of the weight of the three columns of water sustained by these pistons, the radius of the crank being $\frac{1}{12}$ that of the wheel. The diameter of the pump-barrels is 10 feet, and that of their branch 3; thus its circle will only be expressed by 9, while that of the pistons will be 100, a defect common to all forcing-pumps, and which is considerable in the present instance, on account of the bends in the branches, which prevent the water from rising, and consequently require a greater amount of power than is possessed by these pumps. As this increase cannot take place without augmenting the velocity of the current, and that of the wheel does not diminish in proportion, the product of the machine will be much less than it naturally ought to be; in other respects it is simple and well contrived.

Fig. 1846. is a machine for working forcing-pumps, executed at Val St. Pierre, Chartreuse, in Tiérache, 2 leagues from Vervins: it was formerly only supplied by drawing water from a deep well, until 1720, when the book of Chevalier Morland having fallen into the hands of Don Fougeres, then Prior, he seized the idea of that author on the subject of ellipses, which he proposed to use in place of the crank to work pumps, and applied them to a machine driven by a horse to raise water from a well to a height of 150 feet. The machine consists of a turning post I, carrying a cogwheel, which engages a lantern, whose axle carries three equal and similar ellipses N, in whose circumference is a channel similar to that of a pulley; these ellipses are so placed, that if brought together the extremities of their greater axes would form the six angles of a regular hexagon. O is a post in whose summit are three slits, through which pass as many balance beams P, S, traversed by a bolt serving as a common axis; to keep them in the same direction they are maintained by frames, T V, attached to a joist: one of the extremities of each beam is held by two braces, S, Q, between which are rollers R, which work in the channels of the ellipses; at the other extremity X are suspended the rods X Y, of three pump-barrels, placed in a small vault, to which they are attached by iron cramps. The branches pass from the pump barrels through the vault to the reservoir by an inclined plane of 1200 feet. To understand the play of this machine, suppose the horse attached to the swing trees and having his halter attached to the guide bar; when he advances, he turns the wheel and lantern M, and consequently the ellipses which move the balance beams by the difference of their axis; for when the great axis is vertical, the centre of the rollers is raised to a height equal to half the difference between the greater and lesser axis; when this axis becomes horizontal, it descends the same quantity: thus each roller goes over half the circumference of an ellipsis, and during each revolution the piston sucks and forces twice, the rollers never quitting their channel, because the part O Q of the balance beams bears by its length and weight on the resistance of the other part P O: each ellipse may be regarded as the union of four inclined and curvilinear planes turning round a fixed point, and at each revolution a plane compels the weight to ascend from the foot to the summit; a second succeeds, down which the weight descends by its own gravity; it then rises up the third, and falls down the

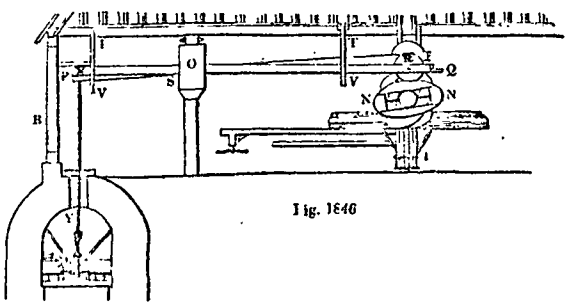


Fig. 1846

fourth. The three being never in the same situation, while one of the rollers mounts the two others descend, after which one descends and two mount, the pistons sucking and forcing accordingly six times during each revolution of the axle, whilst they would only play three times during one revolution of a crank: thus ellipses have the advantage of doubling the velocity of the pistons, and of rendering the action of the power more uniform, because the angles formed by the axes of the ellipses are only 60°, or half those formed by the simple crank.

The great wheel of this machine is 6 feet in radius from the centre to the teeth; the teeth, 101 in number, are 16 inches long, project 4 inches, are $3\frac{1}{2}$ wide, $2\frac{1}{4}$ thick at the top, and $2\frac{1}{4}$ at the base; the axle is 18 inches in diameter: in order that the horse in turning may pass under the axle L K of the lantern, the summit of the teeth of the wheel must be raised $5\frac{1}{2}$ feet above the ground; the shaft or lever must be 14 feet long from the centre of the turning shaft to the attachment of the swing-trees, and the horse should have a clear way of 18 feet radius: the spindles of the lantern are 20 in number, and $2\frac{1}{2}$ inches in diameter; their centres form a circle 2 feet 10 inches in diameter, and that of the hooping round them 3 feet 8 inches, which is of timber 5 inches thick: the axle of the lantern and ellipses is 16 inches in diameter; the ellipses are 6 inches apart and 7 thick; the channel in their edge is 4 inches wide, and $1\frac{1}{4}$ thick: thus they have two edges forming no part of the length of the axis, which is to be measured to the bottom of the channel, in which is a band of iron to keep the timbers together; the greater axis of the ellipsis should be 5 feet, and the lesser 3 feet; thus half the difference is 12 inches, which is the quantity of alternate elevation and depression of the rollers: the length of the balance beams from the centre of the rollers to the suspension point of the piston rods should be 25 feet, and their scantling 5 inches by 9; their centre of motion should be 9 feet 6 inches above the ground: the wooden rollers should be 1 foot in diameter, and 3 inches thick, with a ring of copper on the edges: the centre of motion of the balance beams should be 15 feet from that of the rollers, in order that the arm nearest the pistons, being $\frac{3}{5}$ of the other pistons, may rise 8 inches, or $\frac{3}{5}$ as much as the rollers. The pump-barrels are $2\frac{1}{2}$ inches inside diameter, and

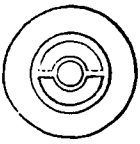


Fig. 1847.

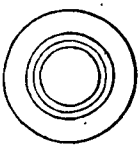


Fig. 1848.

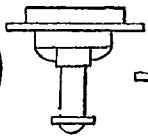


Fig. 1849.

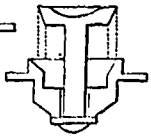


Fig. 1850.

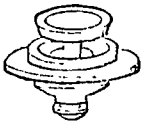


Fig. 1851.

12 inches high; they have four faces, each $3\frac{1}{8}$ inches wide, and are united at the base by a pipe pierced with holes; to admit the water between this pipe and the pump-barrel is a valve, fig. 1847.; in one of the faces of the pump-barrel is an orifice to which the branch is adapted; this branch is only 1 inch in diameter, and comprises a valve similar to the preceding: the pistons, fig. 1852. 1853. are cast-iron cylinders, with a plate of the same metal attached to a double fork, to hold the piston rod, which is a deal batten, 4 inches square. The pistons are composed of two parts, one 8 inches high and $2\frac{4}{12}$ inches in diameter, and the other 4 inches high, and $1\frac{1}{4}$ in diameter: at its extremity is a screw and nut serving to tighten a number of roundles of leather: when the piston sucks, the weight of the atmosphere forces the water to enter the barrel by opening the valve which is at the bottom; the moment the piston forces, the valve closing, the water passes into the branch, opens the second valve, and rises in the discharging pipe. The branches of the pump-barrel being only 1 inch in diameter, while the pistons are $2\frac{1}{2}$, the water is forced into a pipe, which is only one-sixth the size of the piston; and thus the horse employs a part of the force he exerts to overcome the obstacles which are opposed to the water's progress.

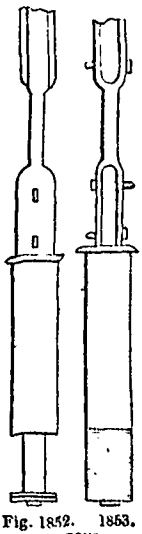


Fig. 1852. 1853.
PISTONS.

Fig. 1854.
PUMP BARREL.

To calculate the Product of this Machine.—The horse performs two turns in a minute, or 120 per hour, and at each turn goes over 88 feet; thus the velocity is 10560 feet per hour: the wheel having 101 teeth, and the lantern 20 staves, it will make $5\frac{1}{20}$ turns whilst the wheel makes 1; and as this latter performs 120 revolutions per hour, it follows that the lantern will make 606 in the same time, and

as each piston forces twice at each turn of the lantern, the three together will make 3636 strokes per hour.

The pistons being $2\frac{1}{2}$ inches in diameter, and 8 inches lift, they force at each stroke a column of water of $39\frac{3}{4}$ cube inches, which being multiplied by 3636 gives 142843 cube inches per hour raised to a height of 150 feet: if it be required to raise water higher than 150 feet, the piston must be diminished in superficies, otherwise the power of one horse would not suffice; if, on the other hand, a less height be required, the superficies of the piston must be increased, or the horse would not raise a quantity equal to his mean strength. To proportion the pump-barrels in either case, the following rule will be found useful: the diameter of the pistons being $2\frac{1}{2}$ inches, its square will be $6\frac{1}{4}$ inches, which, multiplied by 150 feet, gives $937\frac{1}{2}$, and this may be taken for the weight of a column of water forced by each piston; but as the diameter of these pistons might be greater if the pumps were not to a certain extent defective, we may, supposing them to be perfect, take 1000 for the expression of a column of water instead of $937\frac{1}{2}$, and this will still be too low an estimate: this number of feet is then divided by the height the water is to be raised, and the square root of the quotient will give the number sought: for example, if the water is to be raised 60 feet, $1000 \div 60 = 16\frac{2}{3}$, whose square root is $4\frac{1}{12}$ inches.

The pumps may be placed at any convenient height above the water by using suction-pipes to raise the water from a brook or river; the number 1000 must then be divided by the height of the reservoir above the water, and not by its height above the pumps.

M. de la Hire, in his treatise on Epicycloids, has described a very simple method of working pumps, as executed by M. Desargues at the chateau of Beaulieu, eight leagues from Paris.

In fig. 1857., L M O I is a large wheel, placed horizontally, and composed of several pieces of timber firmly united: the axle, A B, of this wheel turns on a pivot and socket, and is kept in its place by a timber framework: the wheel has five wavy teeth on its edge, at O I, which act on the rollers that turn on an axle, C; this axle is carried by an arm, D C, also movable on an axle at D; the arm D C is attached to a portion of a circle, D E F, in such a manner that one cannot move without the other. On the thickness of the arc is a double flat chain, H G, attached at E: this chain has two rings at its extremity, which support the iron stirrup of a forcing-pump. The lever or arm, N, of this machine is let into the axle at B, and may be attached to the wheel for greater strength. There are two rollers similar to the one described diametrically opposed to each other under the wheel, and which ought to act alternately; for when one is in the hollow of the wheel the other is on the wave: but the wheel turning from O to I, the roller will descend from the part O Q, and remount on the opposite side. The part O Q is alone to be considered, for it is that which causes the roller to descend, and raises the piston of the forcing-pump.

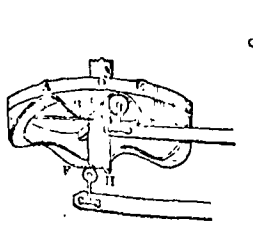


Fig. 1855.

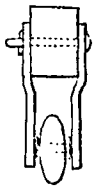


Fig. 1856.

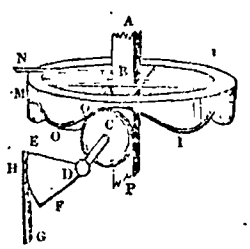


Fig. 1857.

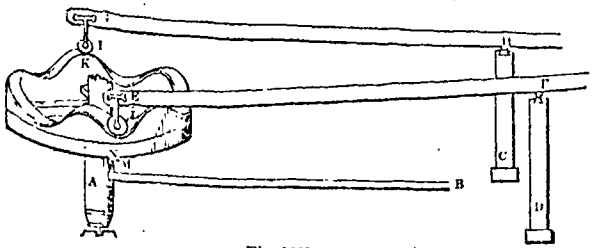


Fig. 1858

The roller remounting on the other part of the wheel makes no effort, but only follows the sinuosity of the tooth, being raised by the weight of the piston as well as that of the triangle D E F, which fall by their own weight. The whole effort of the wheel is due to its weight, so that if it be as heavy as the column of water sustained by the piston, it is evident that there will not be any considerable friction on the pivot P; it must, however, be heavier, so as not to be liable to lifting out of its socket, otherwise it will work on both rollers at once: the number of teeth should be unequal, in order that one roller may always work, and the power moving the lever N act equally, and not by jerks.

Fig. 1855. represents a wheel somewhat similar to the preceding, but the faces A B and C D are straight, being rounded at the summit and base alone: the rollers F are attached to balance beams of a proper length: in this case the pumps are reversed, the pistons forcing upwards, but if a different arrangement be desired, the wheel may be made to work as in fig. 1858; and this manner is preferable, as the balance beam may then be of any required length without regard to its weight. After the position of the posts C and D is fixed, in such a manner that the horse is not inconvenienced when turning, the length to be given to E F is known, and the other arm must be two-thirds of this: the height of the posts is so arranged that when the roller I arrives at the summit of a tooth K, the balance beam G H may be horizontal. When the roller L is at the bottom N of the opposite tooth, the angle M L F formed by the vertical M L and the line L F, which joins the centres of motion of the roller and balance-beam E F will be greater than a right angle; wherefore the direction L F of the power, which sustains the weight L on an inclined plane, not being horizontal, it is very nearly to the weight as the height of the plane is to its base: the more the base of the inclined planes formed by the teeth exceeds their length, the less resistance will there be to the rollers; but as the bases cannot be increased without extending the circumference on which they are placed, and so removing the weight further from the centre of the wheel, which may be regarded as the fulcrum of the lever to which the motive power is applied, the power will evidently gain nothing. The base should be twice the height; the roller 8 inches in diameter, rising 12 inches, and the play of the piston 8 inches. The length of the base of the teeth is 4 feet 4 inches comprising the bottom in which the roller rests; this multiplied by 5, gives 21 feet 8 inches for the circumference of the wheel at the middle of its thickness, or 3 feet 10 inches for the external radius. The wheel is constructed as in ordinary mill-work. The inclined planes are attached together by a band of iron 4 inches wide, on which the roller works. Fig. 1856. shows the manner in which the roller is attached to the balance-beam. The rule for finding the proportion the motive power bears to the weight is thus expressed: the power is to the weight raised by the teeth, as the product of the radius of the wheel multiplied by the height of the inclined plane, is to the product of the length of the lever multiplied by the base of the same plane. Supposing the lever A D to be 14 feet long, and the force of a horse to be 180 lbs., we shall have $3\frac{1}{2} \times 1 : 14 \times 2 :: 180$ lbs., or $1 : 8 :: 180$ lbs., showing that the power is one-eighth of the weight, which will consequently be 1440 lbs. Now, since in a state of equilibrium, this weight should be to that of the column of water in the reciprocal proportion of the arms of the lever, or as 2 to 3, the motive power will only be one-twelfth part of the weight of the column which each piston forces, equal to the weight of 2160 lbs. To find the diameter of the piston, multiply the weight of the column of water each can force by 1728, as a constant number: multiply the height the water is to be raised in inches by 55, another constant number: divide the first of these products by the second, and extract the square root of the quotient, which will be the diameter required. Since a horse can easily make 120 turns in an hour, and at each turn the pistons force ten times with a stroke of 8 inches, they will raise 1200 columns of water 6 inches in diameter 8 inches high, in one hour. The cost of this machine is moderate, and it may be made to draw water from a very deep well, by using suction-pumps at 25 feet apart.

Bascule used by Perronet at the bridge of Orleans, was worked by twenty men, ten being placed at each end; 150 motions were given to it each quarter of an hour, and at each, 4 cubic feet of water were raised 3 feet high, or 2400 cubic feet per hour.

The Chapelets employed at the same bridge were placed vertically, and from 12 to 18 feet in length, and about 6 inches in diameter: four men worked the winches, and were relieved every two hours; they made 20 to 30 turns in a minute, according to the height to which the water was to be raised; 500 cubic feet of water, or $62\frac{1}{2}$ muids, were raised per hour, and at each turn $4\frac{1}{2}$ feet of the chain were wound round.

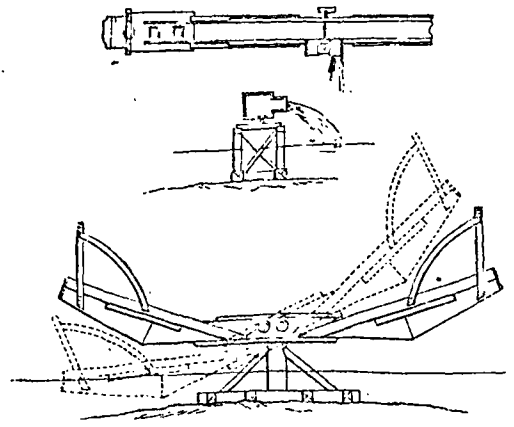


Fig. 1859. BASCULE USED AT ORLEANS BRIDGE.

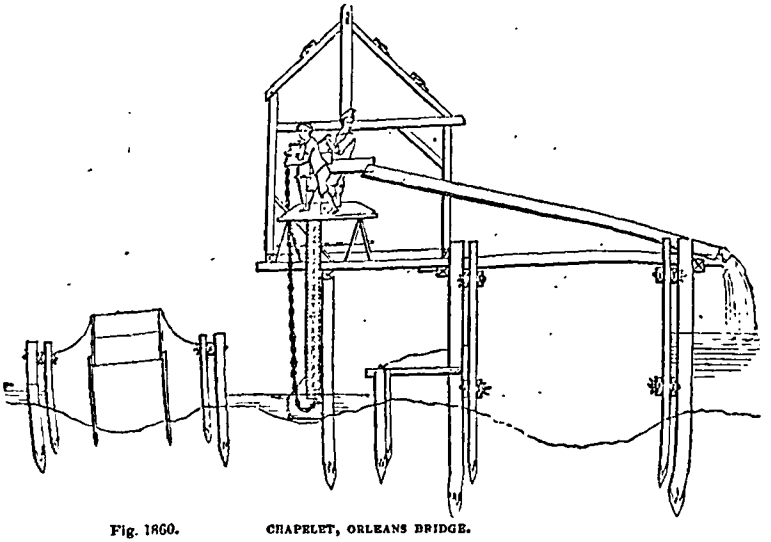


Fig. 1860. CHAPELET, ORLEANS BRIDGE.

The Persian Wheel is a double water-wheel, with float-boards on one side and a series of buckets on the other, which are movable about an axis above their centre of gravity: the wheel is placed in a stream, which puts it in motion by acting upon its float-boards: as the wheel turns, the movable buckets dip in the water, and ascend filled with it: when they reach the highest point their lower ends strike against a fixed obstacle, so as to oblige them to empty themselves into a reservoir placed at the top of the wheel.

Drum or Persian Wheel, employed by Perronet, raised the water 8 feet, but its product varied according to the different depths at which it worked: when at 1 foot, 12 men, relieved every two hours, gave two turns in a minute, and at each turn 24 cells were emptied, each containing $1\frac{1}{2}$ cubic feet, giving for the hour 4320 cubic feet, or 540 muids:

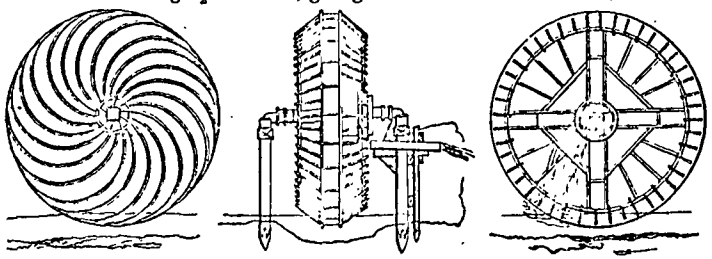


Fig. 1861. Fig. 1862. PERSIAN WHEEL, ORLEANS BRIDGE. Fig. 1863.

when at 9 inches of depth the same number of men made 150 turns in an hour, but raised only 450 muids: when at 6 inches depth, they made 180 turns in an hour, and raised 405 muids: when at 3 inches in depth 180 turns were made in an hour, and raised 270 muids in an hour.

The Scoop Wheel is intended to raise water through a height equal to its semi-diameter, and consists of a number of semicircular partitions, which are open at both ends, viz. at the circumference and at the centre of the machine: as the wheel turns round, the scoops take up the water, which gradually descends during the rotation of the wheel, till it runs into its hollow axle, which again discharges it into a spout.

Chain Pump, as the *Spanish Noria*, consists of an endless chain passing round a wheel, and after entering the water to be raised, returns through a tube into a cistern: the chain carries a number of flat cylindrical pistons, of nearly the same diameter as the tube, one half of each piston being received into openings in the circumference of the wheel; when the wheel is put in motion, the pistons enter the barrel, and pushing the water before them, raise it into a reservoir; and if the wheel is made to go round rapidly, the barrel is generally filled with water. Pumps of this description when put in an inclined position will raise a considerable quantity of water; the inclination in which their power is the greatest is

that of an angle of 24° 21′. In Spain the Noria is usually furnished with earthen pitchers, between two ropes in place of a chain.

The Cellular Pumps are of this kind, and when stuffed cushions are used instead of pistons, they are termed Paternoster pumps.

Chapelet, worked by Horses, at the bridge of Orleans. Twelve horses were employed at one time, making 140 turns per hour; but as some allowance is necessary for changing, we can only calculate upon 120: the number of cogs upon the wheel was 115, that of the great lantern 12, that of the small 8, making in all 9660 buckets of water delivered per hour from each of the two chapelets: the heights of the buckets were 6 inches, their distance apart 6 inches, and the width of the trough 7½ inches.

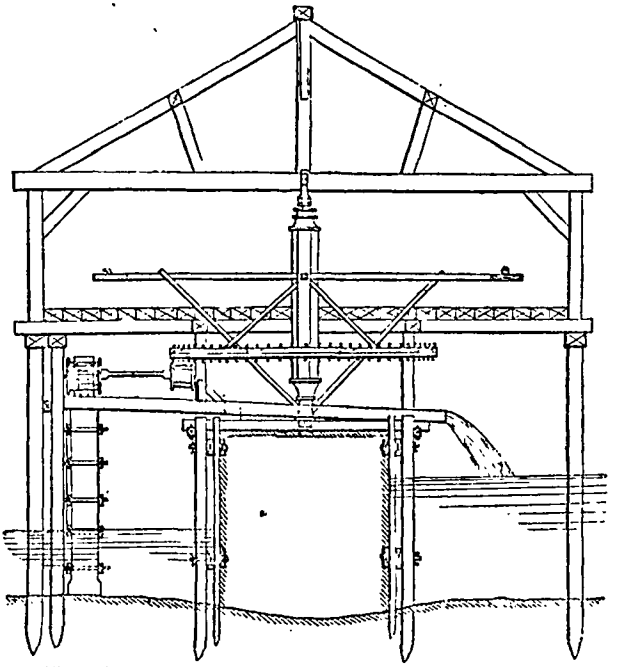


Fig. 1864. CHAPELET AT THE BRIDGE OF ORLEANS.

Chapelet worked by a Water-wheel, at the bridge of Orleans. When the water was 18 inches above low water, the great wheel made 165 turns in an hour, which gives about 2

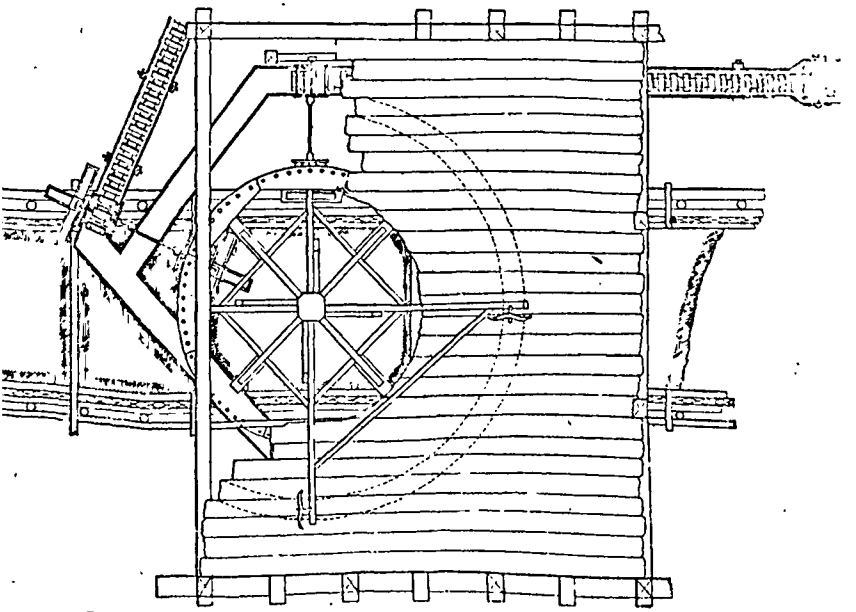


Fig. 1865. PLAN OF CHAPELET.

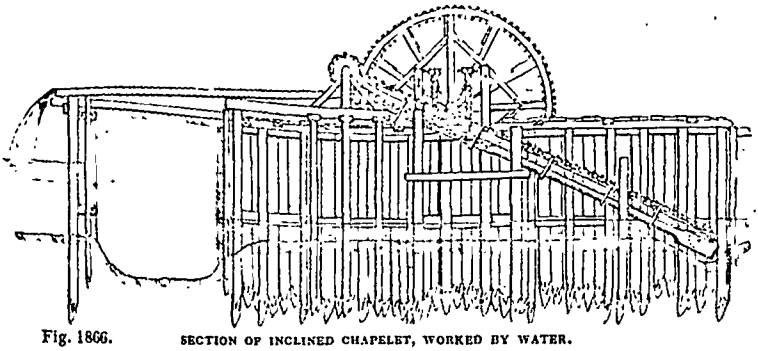


Fig. 1866. SECTION OF INCLINED CHAPELET, WORKED BY WATER.

feet velocity per second, and 6 feet for the current: when the river was 2 feet above low water, the wheel made 180 turns per hour: when it made 165 turns, the troughs were plunged 30 inches; when from 216 to 240, they were only in the water 15 inches. The great wheel had 124 cogs, and the lantern which it turned 15 trundles: the other lantern over which the chain of the inclined chapelet worked, had eight trundles, each of which passed one palette of the chapelet; giving $66\frac{2}{15}$ palettes for each turn of the great wheel, 180 of which it made in an hour, giving a total of 11,904 palettes, each of which brought up 290 cubic inches of water; the whole producing in an hour $1997\frac{1}{7}$ cubic feet raised 12 feet.

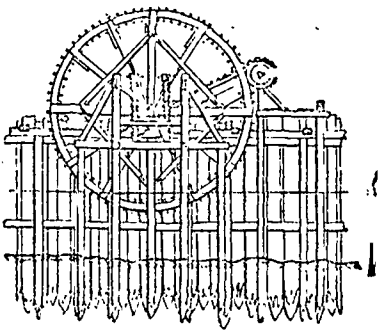


Fig. 1867. ELEVATION OF INCLINED CHAPELET.

The vertical chain pumps employed at the bridge of Orleans gave for the useful effect of each man, during twenty-four hours, 139 cube metres of water raised 1 metre: but many experiments have been since made, and it has been found that 128 cube metres of water raised a

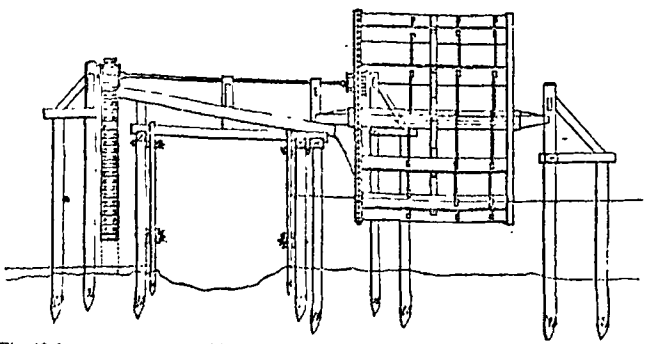


Fig. 1868. END ELEVATION, ORLEANS BRIDGE.

metre is nearer the result. The daily action of a man working at the winch being 155 cube metres of water raised the same height, the relation between the useful effect and the force expended is 0·826. The vertical chain pump is, however, a very serviceable machine, as there is not more than one-fifth part of its force lost: the chain-pump is easily taken up and replaced, and can readily be repaired.

The great Bucket-wheel employed by Perronet at the construction of Neuilly Bridge was 16 feet 6 inches in diameter, and 4 feet 6 inches in width, furnished with 16 buckets and 118 cogs. The wheel with float-boards was 18 feet in diameter, and had 128 cogs; the float-boards, 20 feet in length and 3 feet in width, made an angle of 15 degrees with the radius, to diminish the resistance of the water as they turned: generally the lanterns of 4 feet in diameter had 30 trundles, and the tree was 12 inches in diameter; the length was regulated according to circumstances; some were 38 feet, and from 54 to 108

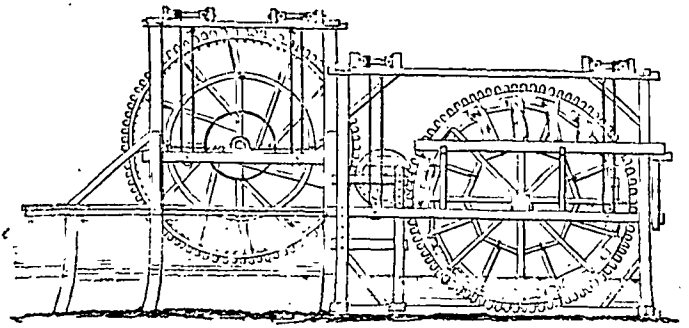


Fig. 1869. ELEVATION OF GREAT BUCKET-WHEEL.

feet in length. The bucket-wheel was mounted on a strong frame, and the wheel with float-boards had an axle 108 feet in length, 20 feet of which was appropriated to the float-boards, which were 18 feet in diameter at the wheel.

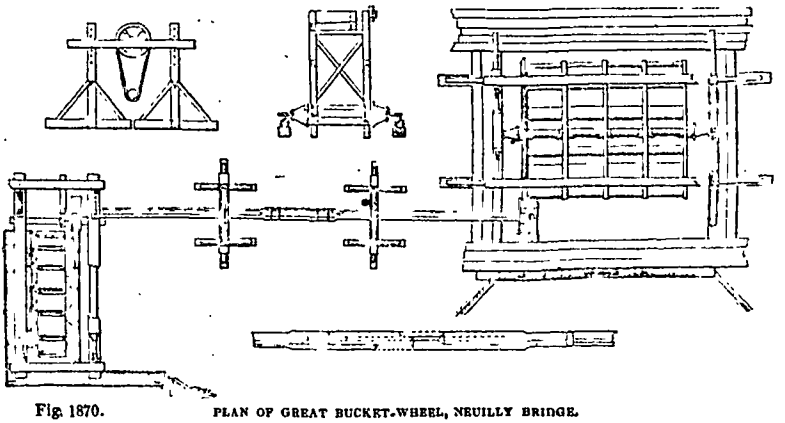


Fig. 1870. PLAN OF GREAT BUCKET-WHEEL, NEUILLY BRIDGE.

Fig. 1871. shows the celebrated Machine de Marly, executed by Rannequin, a native of Liege, by command of Louis XIV.: it commenced work in 1682, and is said to have cost 320,000*l*. It was situated on the Seine, between Marly and Lachaussée, and consists of 14

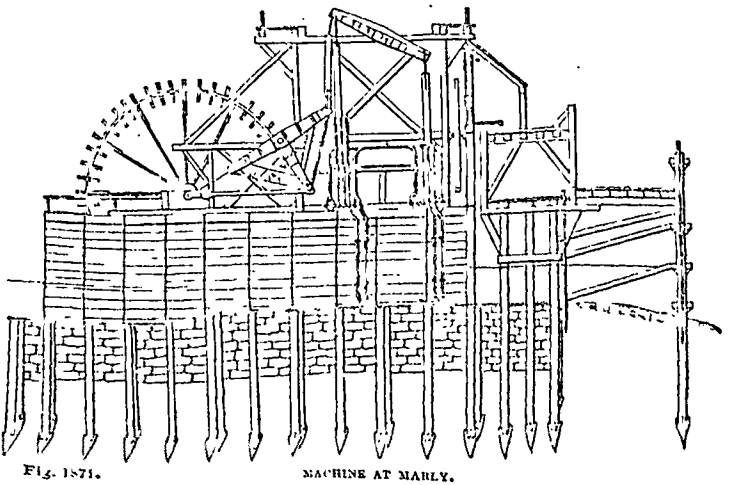


Fig. 1871. MACHINE AT MARLY.

water-wheels, which first raised the water from the river to a cistern 150 feet high and 600 feet distant, then worked the balance-beams of the pumps, which raised the water to a second cistern, 175 feet above the first, and 1944 feet from the river; from thence it was lifted by other pumps to a strong tower or reservoir, 502 feet above the river and 3684 from it; whence the water was conveyed by an aqueduct to the great reservoirs which supply the gardens of Marly and Versailles.

Fig. 1871. is a longitudinal view or section of one of the 14 wheels: on the bed of the river a floor was laid on piles filled in with masonry, and 14 feet above this was the platform which supported the pumps. To the axle of the great wheel a crank was attached, which communicated motion to the balance-beam, and this worked the piston rods of four pumps on each side, which sucked and forced the water alternately. To prevent the air from entering the pump-barrels, a fifth suction-pump raised water to a cistern a little above the four others.

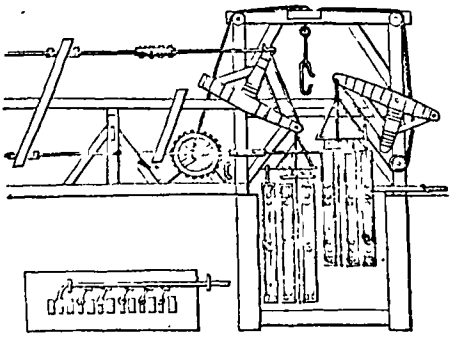


Fig. 1872. MACHINE AT MARLY.

Fig. 1872. shows how these pumps at the first and second cisterns were worked: a crank on the other end of the axle of the great water-wheel communicated motion to the two iron chains, and these, by means of two other cranks, alternately worked the two iron frames to which the piston rods of six pumps were attached. All these pumps worked independently of each other, and each reservoir had six pumps for the purpose of supplying it when reparations were required. The whole system may be drawn up by the crab shown in the figure. The pulley in the middle may be moved into any position along the head of the frame, by means of the winch at the side.

Fig. 1874. is one of the eight suction and forcing-pumps put in motion by the crank of the great water-wheel; when the piston ascended, the water from the river rose in the suction pipe, opened the first valve, filled the whole of the horizontal pipe and a part of the barrel: when it descended, it forced the water in the barrel, which by its pressures closed the first valve, opened the second, mounting in the branch; when the piston remounted, the second valve closed, and the first reopened to admit more water; B represents one of the suction-pumps, which supply the small cisterns to keep the eight pump-barrels from leakage.

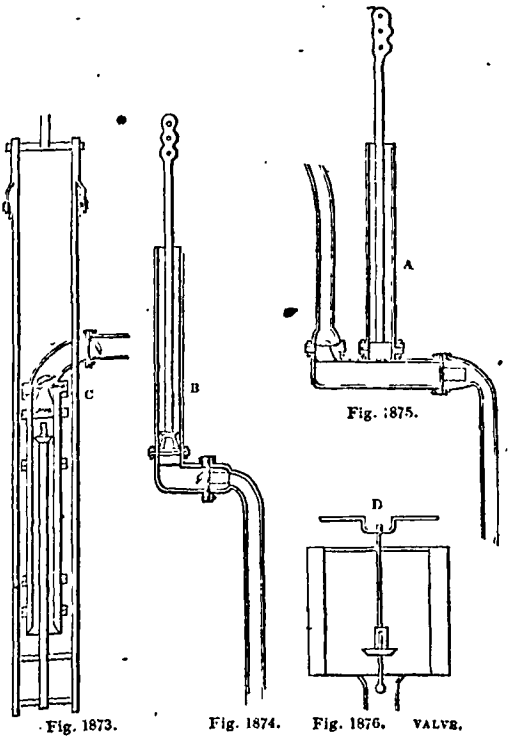


Fig. 1873. Fig. 1874. Fig. 1875. Fig. 1876. VALVE.

Fig. 1873. is one of the pumps of the first and second cisterns: the barrels were carried on iron bars, and the piston rod attached to an iron frame; at the upper part of this latter are shown two small rollers to facilitate the operation of drawing the whole up. The manner of working is the same in this example as previously explained, when on the description of

forcing and suction-pumps, and the valves operated precisely in the same manner. D is a valve at the bottom of each cistern to empty it, which was effected by simply turning the handle at the end of the rod: when the machine was in full work it threw up 168264 cube feet in 24 hours, and employed 60 workmen to keep it in condition.

Fig. 1877. is a machine invented by Belidor for raising water by means of a fall. The water from the source is discharged into the cistern C, at whose lower part is a pipe C D, 10 or 11 feet high, kept continually full. The water on issuing from the pipe C D is divided into two unequal parts, of which the lesser passes along the pipe G H, and up G L, into the cistern M, and then down the pipe M N to the cistern of distribution; the space F E comprises the machine represented in detail at fig. 1878. A B C D, E F G H, are two pump-barrels united by a pipe, I K E G, open at L M N O to facilitate the motion of the pin which passes through the piston rods R and S, whose stroke is limited by M L and N O. I is the pipe marked C D in the preceding figure, having two branches at right angles to each other: the first, I Y, joins the communication pipe Y V, which conducts water into the small pump-barrel, and the second, T Z, is united to a cock, which admits it to the large one. This cock has three conical branches; the first is united to the pump-barrel, the second introduces the water which gives impulse to the piston, the third facilitates the escape of the same water: the tap of this cask acts at two separate times, making a quarter of a revolution at each, to the right and left, communicating alternately with the pump-barrel and the discharge pipe, so that the water escapes from the former while the supply pipe is closed by the solid part of the tap P.

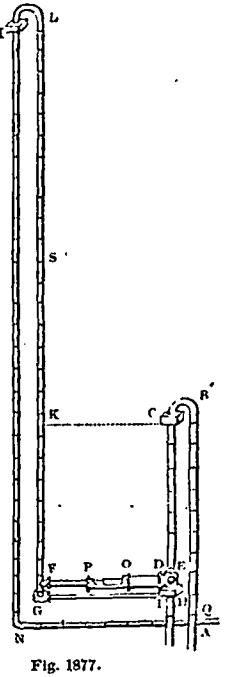


Fig. 1877.

Fig. 1879. represents this cock in detail: A is a plan of the three conical branches; B is a section through the two opposite branches; C a section at right angles to the preceding, and D is the elevation behind; E is the plan of a jacket between the cock and the branches to prevent leakage; G is a section, and H an elevation of it, showing that its bottom is slightly convex, and that the tap may not touch it, but turn on a pivot in its centre; F is a plan of the tap, I a section, and K an elevation of it; L is an elevation of the whole put together, and M a plan and section of its head.

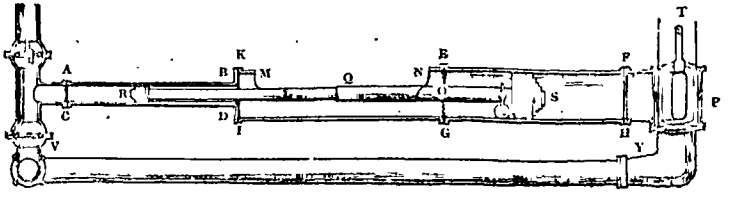


Fig. 1878. BELIDOR'S MACHINE.

Fig. 1880. shows the pistons of this machine, B being an elevation, and M a section: both rods consist of hollow cylinders, the less sliding in the greater, as to shorten the entire length for the purpose of introducing them into the pump-barrels; at each end is a screw; A and C, to which the pistons are attached: the pistons themselves, D E F, I K L, consist of a cylinder on which several leather rings are placed, and a washer and nut to tighten them: to diminish their friction, each is provided with a roller G and H.

The play of this machine will be understood by a reference to fig. 1877. The water in the pipe C D having free communication by H G will rise as high as K: the valves shown in fig. 1878. being pressed upwards, open to allow the water to pass; in doing this it will also enter the small pump-barrel, and drive the piston R towards B D, and consequently S towards the cock, supposed as at fig. 1877., where the pipe of admission closes and the discharge pipe opens, the air or water in the great pump-barrel can escape: when the piston S arrives at F H, the cock making suddenly a quarter of a revolution, and opening the supply pipe and closing the escape pipe, the water from the source will drive the piston forward: for if we suppose its circle six times that of the lesser, there will be six columns of water equal to K F, acting together against and driving it towards N, the water in the

small pump-barrel, at the same time closing the lower and opening the upper valve in the pipe G L. The axle Q having now arrived at M L, the cock will make a quarter of a

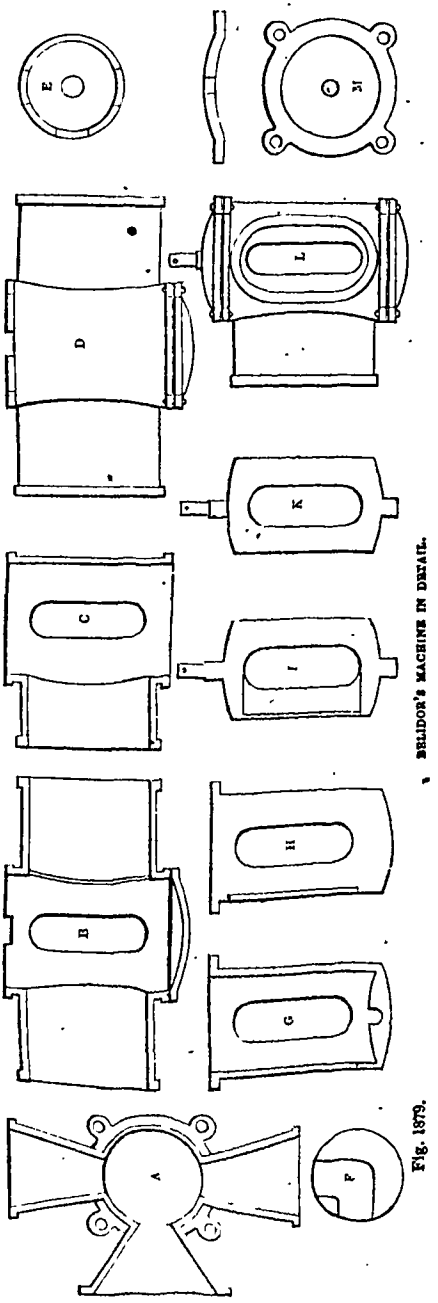


Fig. 1879. BELIDOR'S MACHINE IN DETAIL.

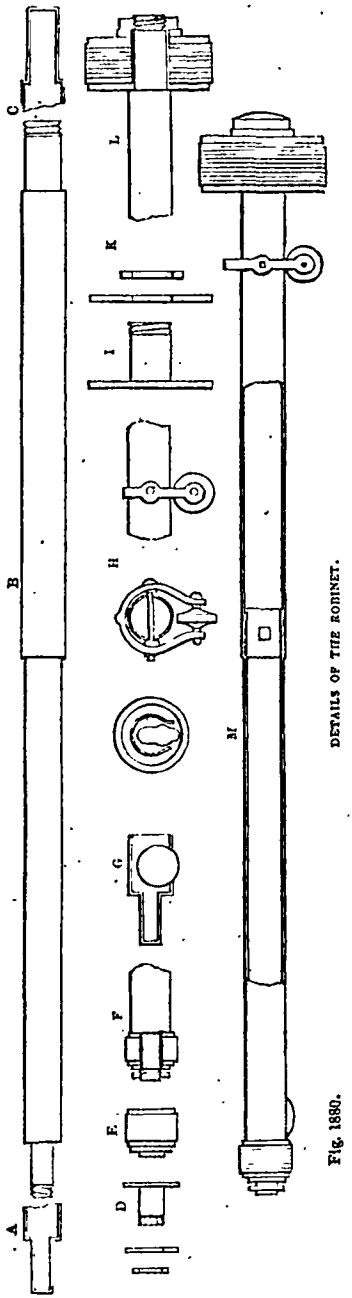


Fig. 1880. DETAILS OF THE ROBINET.

revolution in the opposite direction, closing the supply pipe and opening that of the discharge; the water in the great pump-barrel will cease to act against the piston S, and at

the same time that in the pipe G L, being no longer forced, will close the upper valve; the water in the pipe of communication Y V, driven by that from the cistern C, will open the lower valve in G L, again drive the piston R towards B D, while the other S will in its turn force that which had driven it forwards until the axle Q having arrived at N O, will make a quarter revolution, closing the escape and opening the supply pipe: this will again permit the water from C to drive the great piston, forcing that in the small barrel as before, closing the lower valve, and opening the upper. Thus the alternate motion of the cock will make the water rise to the cistern M, provided the product of the circle of the small cistern, multiplied by the height of the column F L, be less than the product of the circle of the great piston multiplied by the height of the fall C D.

Fig. 1881. shows how the cock is opened and shut alternately. The whole machine is carried on stout timbers, to which are attached two uprights supporting an iron spindle C D: on this as a centre an iron right angle O V H I revolves; the arms G H, K I, have claws at

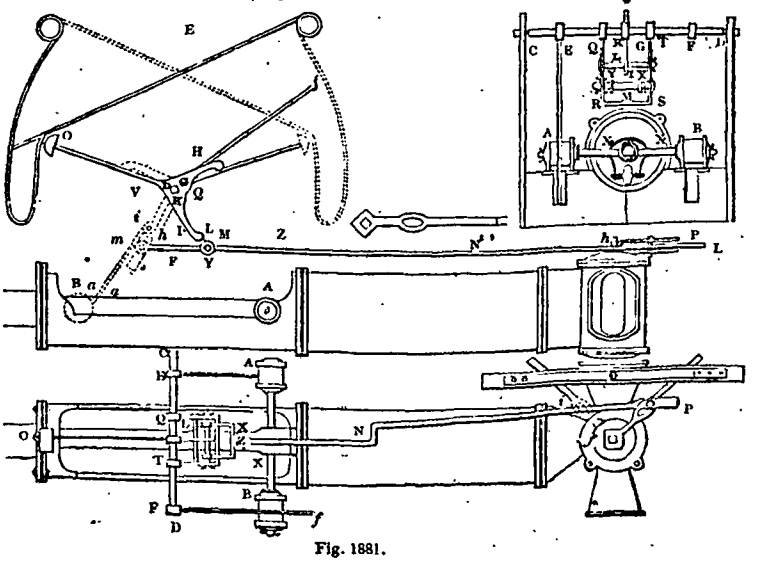


Fig. 1881.

their extremities, and the rod V O a weight, at O, of 9 or 10 pounds; this turns with the axle C D. A stirrup Q R plays on it, the axle being rounded at the rings Q and T. The iron rods E A and F *f* also move with the axle C D. The stirrup is traversed by two bolts L and M, the second of which passes through the branch Z of an iron fork, having a tail Z N P attached, the extremity of which works the key of the cock, which is prevented from going too far by a brace O. The rod X traversing the two pistons has a roller A B at each extremity, which alternately driving the two rods E A, F *f*, before them that move the axle C D, and consequently H I V O, but not the stirrup, which remains in its position until moved by the action of the weight O.

Suppose the stirrup in the situation represented by the upper figure, and that the supply pipe be open, in order that the water may drive the great piston forward, the roller A driving the rod E A will raise the weight O towards the right, and when arrived at the point E, the weight having passed the perpendicular will suddenly fall; the claw I K then meeting the bolt L, will oblige the stirrup to pass to the left, and drive the rod L N P backwards, at the same time turning the key of the cock; thus directly the axle X arrives at its extreme point to the left, the escape of the weight will shut off the supply and open the escape-pipe. The rod F *f* having performed the same operation will be driven forwards by the roller B, in the same manner as the preceding, because the escape-pipe being open, the small piston will be driven back, and the weight O raised to pass from right to left: when it is a little beyond the perpendicular, the claw I K will take up its first position, meet the bolt L, drive the stirrup forward, thereby turning the cock, closing the discharge and opening the supply pipe, the water from which will again drive the great piston, and cause it to execute its first operation.

The axis C D should be placed at the middle of the open barrel, so that the three points *a*, D, A may form an equilateral triangle in the same plane, whose base *a* A may be equal to the course of the rollers between the points where they touch the rods E A, F *f* when they

arrive at the points which mark the stroke of the piston, in order that the distance from the centre of the axle D to the centre of the bolt M may be equal to the course M*m* or *ki* of the bolts M*h*.

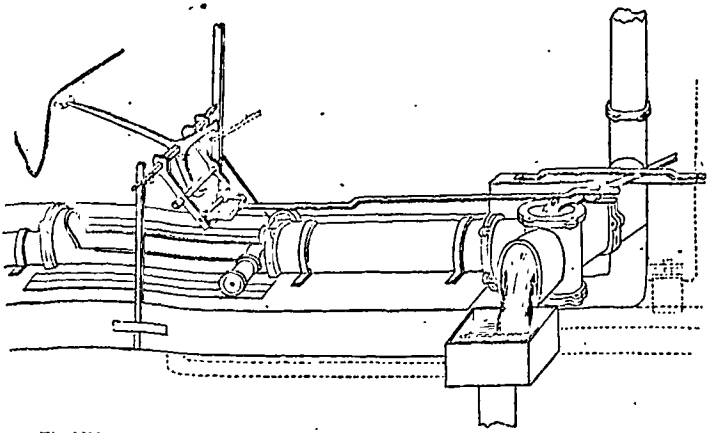


Fig. 1882. BELIDOR'S MACHINE.

The calculation of the dimensions and effect of this machine is based upon the following data: that the fall C D in fig. 1877. is 10 feet, the height F L of the pipe for raising the water to the cistern M is 50 feet, the stroke of the piston 30 inches, and its velocity 1 foot in a second of time; the resistance caused by the weight and friction of the machine must be taken into account, or be considered as raising the water 60, instead of 50 feet. The great piston is 10 inches in diameter, the lesser 3½ inches, the discharge pipe 4½ inches in diameter: the product of this machine will be about 793 cubic feet per hour.

Machines made use of by the engineer for pumping out foundations require arrangements to be provided, which are perfectly independent of raising the water, and the first object when selecting a contrivance for such a purpose is to discover where the useful effect is the greatest, with regard to the force expended by the moving power; sometimes, however, it happens, that machines for pumping, apparently defective, may be used very advantageously: men were employed with pails and scoops, at the bridge of Orleans, in the first experiment made by Perronet, and it was found that each man raised with a pail ·0034 cube metres of water per minute, at 1·79 metre of height, and in a second experiment ·0069 cube metres of water at 0·97 metres of height in the same time, which in the first result amounts to 3·652, or the second 4·016, and mean 3·834 cube metres of water raised per hour one metre high: the workmen laboured 12 hours, so that the useful effect produced during the 24 was 46 cube metres of water raised 1 metre: the pail contained ·0018 cube metres, but as the workman filled it one-fifth was lost before it was discharged out of the foundations; we must only estimate 55·111 cube metres of water poured out of the pail 3062 times. The weight of the pail is equal to ·004 metres cube of water, and this raised 3062 times furnishes a quantity of action of 12,248 cube metres of water, which added to the other gives 67,359 cube metres: a man using a wheel can raise about 200 cube metres of water 1 metre in height in a day's work.

In the Chapelet at Rochfort, mentioned by Belidor, moved by 4 horses, 44·4 cube metres of water were raised 7·8 metres high per hour, which makes the useful effect of each horse 86·6 metres of water raised a metre in an hour; and supposing the horse to work 8 hours, the daily useful effect would be 693 cube metres of water raised a metre: but if we suppose that the machine consumed two-fifths of the moving force, the quantity of daily action of each horse would be 1156 cube metres raised a metre.

Water Wheels moved by the stream have very variable effects: according to Smeaton two-thirds of the force is generally consumed by the resistance of the wheel, and only therefore one-third is transmitted to the shaft: the Archimedean screw only gives for the useful effect a little more than half the force it consumes, and the French engineers assert that the *roue à tympan* is one of the most advantageous powers that can be made use of for pumping.

Spiral pumps, as improved by Bernouilli, were introduced with considerable effect at Moscow, where one raised a hogshead of water in a minute to the height of 74 feet, and through a pipe 760 feet in length: among the variety of forms given to them, it has not been yet sufficiently proved which is the best; some engineers giving the preference to the cylindrical plane, others to the conical: at Florence the machine most used had its spiral cylindrical; its diameter was 10 feet, and that of the pipe 6 inches. Eytelwein recom-

mended this machine to the attention of the engineers; its enlarged part occupied three-fourths of its circumference, and was nearly 8 inches in diameter at the outer end; the enlarged portion contained 6844 cube inches, and the spiral revolved six times in a minute, raising in that time 22 cubic feet of water 10 feet high: when Dr. Young made his experiments upon the Archimedean screw, he found that it required such a length of pipe, that it became inconvenient when the water was to be raised to any very considerable height.

MM. Denisard and de la Dueille executed at Sevres, between Paris and Versailles, a machine for raising water by a natural fall, shown in fig. 1885.: it consists of a wooden framework in which is a basin with two boards placed on each other, and hollowed out to form the basin, which is lined with leather; in it is a piston of nearly the same diameter, attached thereto by a piece of leather, in such a manner as to have a stroke of only 3 or 4 inches: four pipes are adapted to this basin; the supply pipe I T, the branch Z Z, the waste F, and the descending pipe G. The long screw with two nuts Y, N, raises and lowers the balance-beam consisting of two basins O, Q, with pipes of communication to allow the water to pass from one to the other: at the extremities of this balance-beam are rods which open and shut valves in the waste and supply pipes: these are represented in figures 1883. 1884. The valve is enclosed in a small coffer, A B, in which is a truncated cone, fitted to the pipe. The cover of this cone is attached to an axle C, and this latter to the rod E, which the balance-beam works. The part I of the valve (fig. 1883.) being stopped by the cone, and the whole valve being immersed, the column of water to be raised is in proportion to the diameters of the bases. When the rod E descends, the solid cone, which has a contrary motion, will unstop the hollowed cone I, and the water will without difficulty pass into the tubes D, R; if, on the contrary, the water raise the rod E, the valve closes, and the pipe will be stopped. The source L being 10 feet high, the water will introduce itself by the pipe I T V below the piston A, which being driven by this water will naturally rise, at the same time driving out the water above at B, through the waste pipe F; by this elevation the nut N raises the balance-beam, and the water passes from the basin O to Q; the extremity O raises the rod R, which closes the valve H; the basin Q resting on the rod S opens the valve X, in the descent pipe G, and the water from the source, taken from below the great piston, rises by the branch Z Z. The pipe V being stopped, the piston is loaded with the weight of water in the descent pipe G: by its descent the balance-beam is drawn down, and the water returning from Q to O closes the valve X and opens H: the water is thus raised in succession.

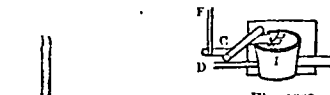


Fig. 1883.

Fig. 1884.

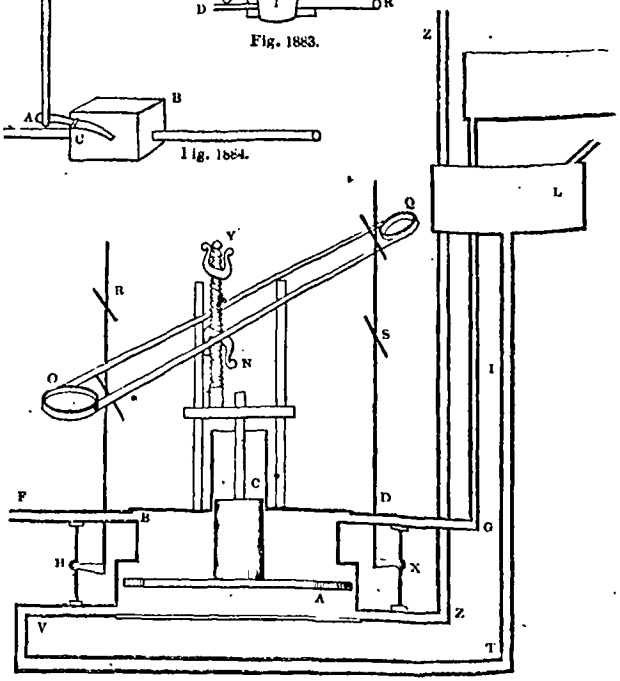


Fig. 1885. DUEILLE'S MACHINE.

Some alterations were afterwards made in this machine in order to raise the water in a continuous stream; this disposition is shown in fig. 1886. The source A furnishes water by the pipe A B C below the lower piston D; this source is supposed to be 10 feet high.

The descent pipe E F G, 30 feet high, admits water below the upper piston H, and tends to raise it: the water compressed below the same piston H is forced up the pipe I L M. The water below the lower piston D escapes by the waste N; the valve O is opened by the rod P; the second acts in a similar manner. The source V, supposed 10 feet high, admits water above the upper piston H: the water in the descent pipe Y Y, 30 feet high, presses on the upper part of the lower piston D, and forces the water up the pipe Z W to a height of 40 feet: during this operation the water contained below the upper piston H escapes through the waste K, the valve T being closed. Thus the machine will force water alternately on each side. The contrivance for opening and shutting the valves is the same as that described in the preceding machine. The upright pipes are furnished with valves to prevent the return of the water.

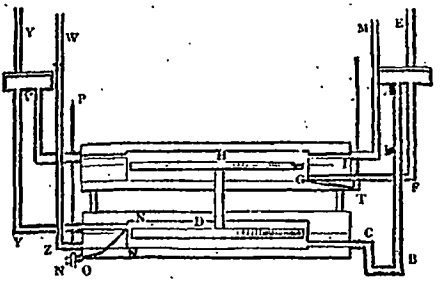


Fig. 1886. SIDE ELEVATION.

Fig. 1887. is a machine for raising water by means of two buckets; one of which, A, is larger than the other B, so that both being full of water, the first in descending raises the second, and the lesser B weighing more than the other, to oblige it to ascend when both are empty. The bucket B has an iron hoop round its middle with an ear attached, and A has a similar circle, Q, at the bottom: the water from a source is conducted to a cistern E, and flows constantly through the waste F; the two buckets are attached to a cord or chain passing over a pulley R, so that when the lesser bucket is in the cistern the other may receive water from the waste F; when the bucket A is full, it descends and raises the other B, as much as its fall; it then catches the hook O, and empties itself into the cistern; at the same moment the ear of the bucket A catches another hook at the bottom of its descent and empties itself; the lesser being heavier than the greater will compel it to mount, and recommence the same manœuvre. On the axle of the pulley R is a toothed wheel S engaging a pinion T, which carries a fly-wheel to preserve uniformity of motion: if the fall C D be less than the height to which the water is to be raised, the buckets K, L may be suspended to two different wheels M, N, whose diameters should be in the reciprocal proportion of the fall and the height the water is to raised; these two wheels must have a common axle, and turn with it. For example, if the fall be 10 feet and the water is to be raised 30, the radius of the lantern M of the lesser bucket L must be triple that of the lantern N of the greater bucket K; but the weight being in the reciprocal ratio of the arms of the levers, the capacity of the lesser bucket must only be one-third that of the greater. Gironimo Finugio is said to have invented this machine at Rome in 1616.

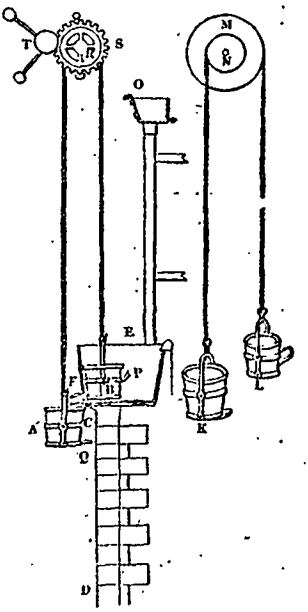


Fig. 1887.

Fig. 1888. is a machine on the same principle invented by Mr. Becket. B C is a fall 10 feet high, C is a well receiving water from the cistern B, which is supplied by a spring; H, I, K are three floors supporting the machine; L M N is a timber frame; O is an axle 3½ feet long, turning on gudgeons, and common to three wheels. The first, P, is 2 feet in diameter and 5 inches thick, and has a groove in its circumference; the second, Q, is 6 feet in diameter, with rebates in its circumference, forming a channel 1½ inches wide, of a spiral form, its greatest enlargement in a single revolution being 2 inches; the third, R, is 3 feet 10 inches in diameter; its circumference has also a circular rebate, enlargement at one revolution being ¾ of an inch. To the wheel P a flat and flexible chain is attached, which, after enveloping the circumference, is divided into two others P, S; to this chain is fixed an iron rod carrying the greater bucket A; the wheel Q has a similar flat chain, so that when it makes one revolution from left to right, its circumference winds up the chain from T to

T^1; the lower part of the chain, from T^1 to T^2, is crossed by small bars, which engage in the rebates of the wheel Q, by which means this part of the chain is prevented from touching that which envelopes the circumference, and an equilibrium is produced between the chain and the rod S S, by the compensation of the arm of the levers produced by the spirals. On the wheel R is a cord, whose other end surrounds the wheel V, 2 feet in diameter; the axle of this wheel is common to another W, 1 foot in diameter, on whose circumference is a cord passing over a pulley, and suspending a weight in a box X at the extremity of the radius of the quarter circle Y, in whose circumference are pulleys which receive the cord from the wheel W; Z is a weight to counterbalance that of the chains, and preserve a perfect equilibrium. On the axle O is a cogged wheel driving a fly to maintain uniformity of motion: at the extremity of the chain is a copper bucket F with a clasp valve in its bottom; the rod S carries the bucket A, which contains three times as much as the preceding; it has likewise a valve in its bottom, opening by means of a catch, which meets a pin in the cistern C; the buckets have copper rollers at their sides which work on the guides *i, i*; when the lesser bucket descends it meets the pin A. which by means of a lever opens a valve in the cistern B, allowing the water to flow into the bucket A. When the smaller bucket F is full, it runs over into the basin G, and thence through B into the great bucket A, until this is sufficiently full; the lesser bucket begins to ascend, and ceasing to rest on the pin the valve in B closes, and the water in the basin G, supplied from the source, runs by a waste pipe into the bucket A, continuing to precipitate its descent. The great wheel Q, which carries the lesser bucket, being 6 feet in diameter, while P, which carries the greater bucket, is only 2, and the fall being 10 feet, the water will be raised 30; when the small bucket arrives at the floor L it is arrested by a catch *f*; at the same time its valve is opened by a pivot at *e*, and discharges its contents into a trough or cistern of supply: at the same time the greater bucket meeting a pivot in the cistern C, which opens its valve, discharges its water through the channel D, both being empty and the lesser the heaviest, it descends and raises the greater, again to perform the same manœuvre. The circumferences P and Q are formed spirally, so that the weight of the chains may always be in equilibrio, but this is more particularly effected by the quarter circle Y, and its weight Z, which acts on the wheel Q when the radius Y Z X is in an horizontal position, that is, when the chain T is unrolled; for as this is effected, the lever Y X approaches a vertical position, and the weight of the chain diminishing the action of the weight X, diminishes also, until the weight Z ceases to act on the wheel R, which happens when the weight contained in X is at the bottom of its box; thus the cord to which this weight is attached is kept constantly stretched. When the lesser bucket begins to descend, the movable weight in X remounts, before any motion is communicated to the lever Y X; but as the chain T unrolls from the wheel Q, its weight increasing and that of S diminishing by rolling on the wheel P, the lever Y X approaching a horizontal position, the weight Z again acts on the wheel R, retarding its velocity and maintaining the proper equilibrium in order to prevent the bucket F descending too fast. The fly-wheel prevents the machine from receiving any shock when the buckets are emptying themselves: this machine works very slowly, only raising the lesser bucket once in 5 minutes: it was constructed in Buckinghamshire, to supply the house and gardens of Sir John Chester,

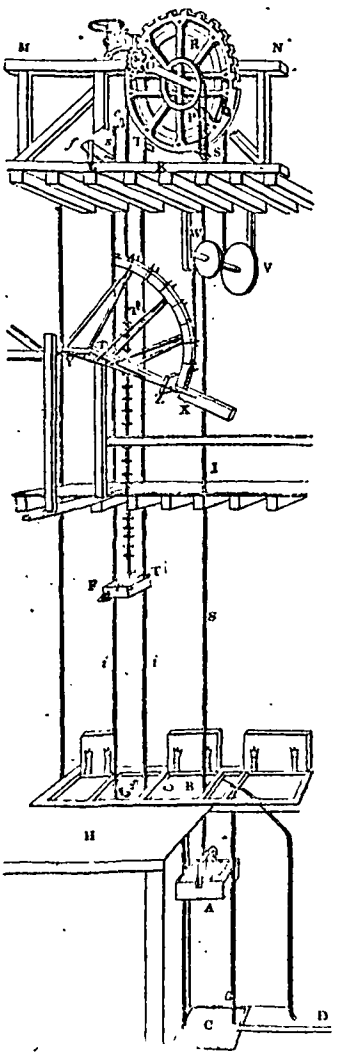


Fig. 1888.

Bart.: the original machine was put up by Mr. George Gervis, but the modification described above is due to Mr. Becket.

Among the machines employed for drawing water from deep wells previous to the general introduction of pumps and hydraulic engines, the following have been selected as the most efficient, and frequently of use to the engineer for temporary purposes.

Fig. 1889. is an apparatus formerly existing at Darés, near Dieppe; although the well is exceedingly deep, it drew a quantity of water sufficient for the consumption of a large garrison in time of war. It consists of an upright axle, with a pinion at its summit, round which a rope was passed twice, to which the buckets were attached; there were six levers to the axle, each 7½ feet long, and as the radius of the pinion was 14 inches, the power was only one-sixth of the weight; therefore six men applying their power to the six levers, assuming each to exert a force of 25 lbs., would raise 13 cube feet of water at once.

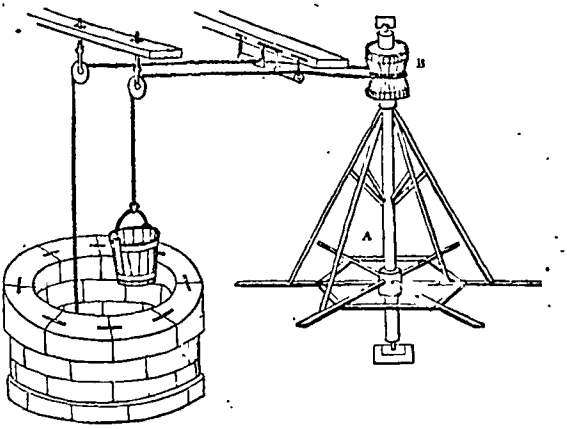


Fig. 1889. MACHINE FOR DEEP WELLS.

The machine represented in fig. 1890. was invented by M. Morel. The weight A of 800 lbs. may be raised by means of the fixed pulley I which sustains it. The cylinder B, 1 foot in diameter, has two toothed wheels C, I, each 24 inches in diameter, the first of which engages the lantern D, also of 24 inches, and the axle of this lantern traverses another 3 feet in diameter, which carries the chain of buckets. The weight is raised by the winch F of 1 foot radius, accompanied by a fly-wheel G and a lantern H, 3 inches in diameter, which engages the wheel I. As there are four lever arms between the power and the weight, viz. the arm of the winch 12 inches, the radius of the lantern H 1½ inch; that of the wheel I 12, and that of the cylinder B 6, the weight will be to the power as 16 to 1; consequently the action of the weight being reduced to 400 lbs. the power will only be 25 lbs., which is the force of a man applied to the winch. While the power turns the winch F and cylinder B, the chain of buckets remains immovable, because the wheel C, which has a spring or catch, is separated from the cylinder; there being four levers between the weight and the power of the respective lengths before mentioned, the weight is to the water in the buckets as 4 to 1; thus the buckets in mounting will raise 100 lbs. of water, or rather less. The net product will depend on the height the water is to be raised, the wheel C and lantern D being of the same diameter, the velocity of the cylinder B will be to that of F, as the radius of the first is to that of the second, or as 1 to 3; consequently, when the cord has unrolled 1 foot, the chain of buckets will have gone over 3: to maintain uniformity of motion, the wheel C engages the lantern K, on whose axle is a small fly-wheel L.

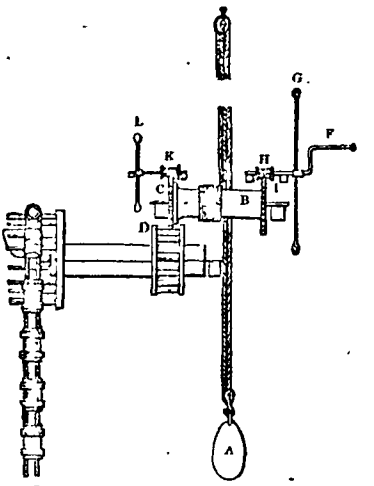


Fig. 1890. MOREL'S MACHINE.

Fig. 1891. is the plan of the cistern of distribution formerly existing at the fountain of St. Catherine at Paris. The upright pipe A brought the water from the pumps of Notre Dame to the circular cistern B C, in the middle of which is a rim D to calm the motion of the water, which flowing through the gauges with which the circumference of the basin is pierced, runs

into the cistern E F, where its motion is further calmed by another rim G; from thence it is distributed by gauges of different sizes into all the basins comprised between E F and H I, having each a pipe at the bottom to conduct the water to its destination: each of

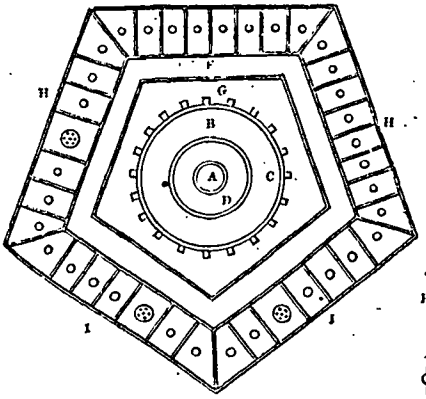


Fig. 1891.

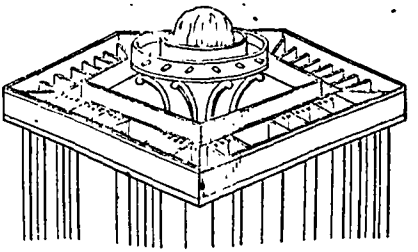


Fig. 1893.

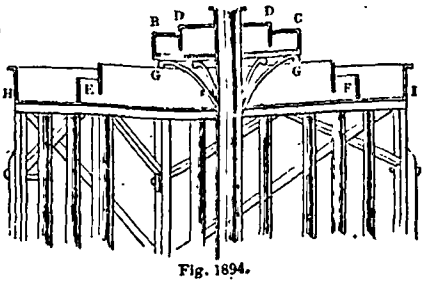


Fig. 1894.

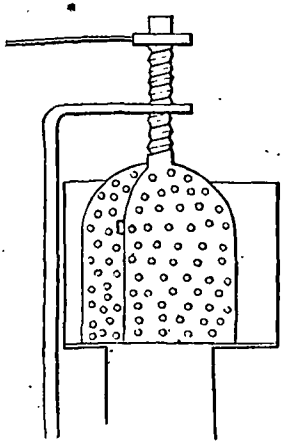


Fig. 1892.

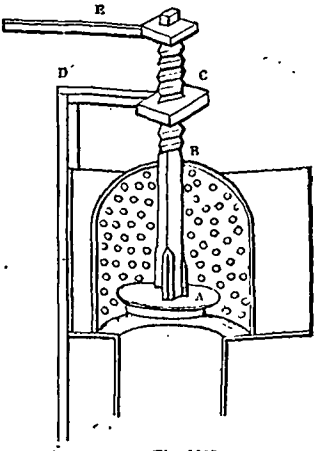


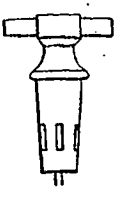
Fig. 1895.

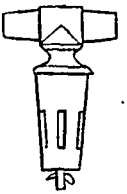
FOUNTAIN OF ST. CATHERINE'S.

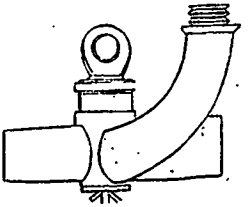
these descending pipes is closed by a valve A (Fg. 1893.), attached to a rod, whose extremity terminates in a screw working in a nut C; the valve is raised and lowered by means of a key E; to prevent extraneous matters from entering, each valve has a cover of metal pierced with holes, and opening on a hinge.

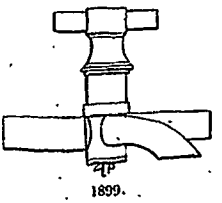
Experiments have been made on the effects of flexures or bendings in the pipes which conduct from the reservoirs of water-works: the pipes were perforated with small holes, to allow the escape of the air, and at each end a tube, 2 inches in diameter, was soldered on, which united with the reservoirs: and it would seem that a curvilinear pipe, in which the bendings lie horizontally, discharges less water than a rectilinear pipe of the same length, and that a still greater diminution takes place when the flexures are placed in a vertical plane. When there is a number of contrary flexures in a large pipe, the air some-

times lodges in the upper portions, and stops the water's motion; air-holes and stop-cocks may be used to prevent this, which can be shut when the water is in its proper condition.


1896.


1897.


1898.


1899.

The forms of cocks usually employed in water-pipes are represented in the several figures, with three branches at right angles to each other; the tube is pierced in such a manner as to shut off or supply the branches, together or alternately; the cocks must always be proportioned to the size of their pipes, and when too large to be turned by hand must be worked by an iron key and lever.

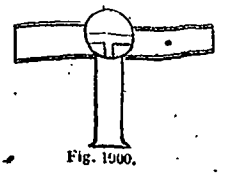


Fig. 1900.

1901.

CHAP. XVIII.

SUPPLY OF TOWNS WITH WATER.

We have already described the methods practised by the Romans for the supply of their towns with water, and also the attention paid to the subject at a very early period in our own capital; but that much yet remains to be done to ensure cleanliness, and consequently health, has been recently proved in the excellent report made "upon the State of Towns and Populous Districts," by Her Majesty's Commissioners: with improved machinery and the aid of the steam-engine, which enables us to raise water with perfect ease and at a small cost to almost any height, we may hope ere long to see the object of the Commissioners fully carried out, in obtaining a plentiful supply of wholesome water for every dwelling throughout the empire. The engineering works for such a purpose would be neither difficult of execution, nor intricate in their arrangement.

The quantity of water given out by a pipe under pressure, when the aperture and head of water are contiguous, is easily calculated; but when the water is to be delivered at a distance, the amount of friction and resistance of the fluid in its passage must be taken into account: practical experience has established many rules to guide us on this subject, which have been generally applied by most of the engineers of our water companies: when a town is so situated that water can be brought from a higher source than where it is required to be delivered, there is no difficulty whatever in regulating its descent; a reservoir must be constructed of sufficient dimensions to contain the ordinary supply, from which the mains are laid, with their branch pipes to the houses or other situations where the water is to be received.

The mains may be kept constantly full by the aid of a cock at the point of delivery: where the water is to be shut off from one part of the town whilst it is running to another, each house must have a separate cistern with a ball-cock, which shuts off the water when it arrives at a certain height, and prevents any waste. To raise the water from a low level to a higher, some additional works are requisite: a steam-engine is employed to throw it to a reservoir upon some high ground, from whence sufficient pressure may be gained to deliver the water to its destination; and when it is to be sent to any point above the level of the highest reservoir, a simple and ingenious contrivance has been made use of, previously to the introduction of which it was found that when the aperture leading to the reservoir was closed, and the engine continued to force the water forward, the excess of pressure burst the pipes. It consists of two upright standing pipes united at the top, and forming a siphon, above which is another upright pipe open at the top, standing up twenty or thirty feet above the reservoir: as this apparatus is connected with the upper supply, as soon as the pressure exercised is greater than that arising from the head, the water will flow out of the top of the pipe into the reservoir below, thus forming a safety-valve.

Where the establishment is small, the forcing-pumps which raise the water are worked either by horses, a water-wheel or steam-engine; but in large works the latter is usually preferred.

It has been before observed that when pipes were first laid down they were bored out of timber, and the taper end of one was inserted within the other, which method did not permit of pressure being exercised. The introduction of cast-iron pipes, united by flanches at each end, screwed tightly together, with lead and other stuffing, has enabled mains to be formed perfectly water-tight: when inserted one within the other, or simply screwed together, a variation in the temperature will in a length of 300 feet produce in winter a contraction sufficient to tear them asunder, some play being absolutely required at the joint.

The materials for closing the joints of the mains and pipes is now generally the best Dantzic fir, cut into shocks of 9 inches in length; these are worked with an axe, or split into pieces 2 inches wide, and ¾ of an inch thick, worked into the proper shape by spoke-shaves, so as to suit the curvature of the socket, as well as the convexity of the pipe to be inserted within it: a piece of fir, 9 inches in length, worked and cut into two, forms a pair of wedges.

The joints are thus made: the wedges are first placed close to each other in the socket, and by means of a set applied to the end of each they are driven tight, and cut off close: should any escape of water take place, a wooden spile is driven in to stop the leak. Another, though more costly method is that of introducing first some gasket, and driving it tight, to prevent the melted lead from passing; then by means of a clay mould running it with lead, and afterwards setting up the joints. Pipes of various bores with wood joints are found to resist any pressure to which they are ordinarily subjected, and less likely to require reparation.

Mr. Robert Thom stated to the Commissioners of Inquiry in 1843 that his plan for supplying towns with water was first to obtain some natural basin, at a sufficient height, either in itself containing a large quantity of water, or into which a great extent of surrounding surface can be drained. This reservoir should be formed deep enough to maintain the water at a low temperature, and prevent the breeding of insects and the growth of vegetables, and capacious enough to hold at least four months' supply: if it be not possible to obtain a sufficient extent of drainage surface at one place, other basins must be sought for to form auxiliary reservoirs, and the waters conducted into the main reservoir by aqueducts furnished with sluices of a peculiarly simple contrivance. To facilitate the collection of the water from the surfaces, catch-water drains must be made use of, and advantage taken of any stream which may be accessible: from the main reservoir the water is to be led by an aqueduct to some place near the town, where reservoirs can be formed at such a height that from them it will rise considerably above the highest houses. These two reservoirs or regulating basins are each to contain two days' supply, and from them the water is carried into two or more self-cleaning filters, and from the filters into two distributing basins; the regulating basins, filters, and distributing basins, being in juxtaposition, and so arranged that one of each may be connected together, to form a set of apparatus, two of which are required, that the one may be in use, while the other is cleansing or repairing. From the distributing basins, the water is carried through the streets by supply pipes of iron, so placed that it shall always flow in one direction, entering at the higher and wider end, and flowing to the lower: they are always kept full at high pressure, so that there may be a supply for every emergency.

Self-cleaning Filters.—That constructed by Mr. Thom at Paisley, with the pure water basins attached, is thus arranged: the stone pipe H brings the water from the regulating basin to the filters, and iron pipes, *p*, communicate between the stone pipe or aqueduct and the top and bottom of the filters.

A valve near the top of the iron pipe S P, at S, forces the water to enter on the top or at the bottom of the filter at pleasure. The filter is 100 feet in length, and 60 feet in breadth, divided into three compartments, which may either act together or separately, so that when one compartment is being cleansed, the other two continue in operation. The site of the filters is a piece of level ground, excavated to the depth of 6 or 8 feet, with retaining walls all round, joined with cement, and puddled behind, so as to become water-tight. The bottom is laid about a foot deep with strong stiff puddle, over which is a pavement so cemented as to be impervious to water. The whole of this bottom is then divided into drains or spaces, 1 foot wide, and 5 inches deep, by means of fire-brick laid on edge, and covered with flat tiles, of the same material, perforated with small holes, like those used in a kiln for drying oats. These holes are placed very near each other, and are rather more than $\frac{1}{10}$ of an inch in diameter; there is also a space of ¼ of an inch left open between the ends of the bricks, which support the perforated tiles, and their upper edges are little more than 1 inch broad, in order that there may be no space without holes, and nothing to prevent the water spreading equally over every part of the bottom of these drains. This is particularly necessary when the filters are being cleaned by the upward motion of the water. The perforated tiles or plates are covered to the depth of 1 inch

with clean gravel, about $\frac{3}{16}$ of an inch in diameter; this is followed by five other layers of gravel, each of the same depth, and each succeeding layer a little finer than the previous one, the last being coarse sand: over this is placed 2 feet depth of clean, sharp, fine sand, similar to that used in hour-glasses, but a very little coarser; about 6 or 8 inches deep of the fine sand nearest the top is mixed with animal charcoal, ground to the size of coarse meal, each particle about $\frac{1}{16}$ of an inch in diameter. A longitudinal drain or pipe, N, runs between the filter and the pure water basin, communicating with both; on each of

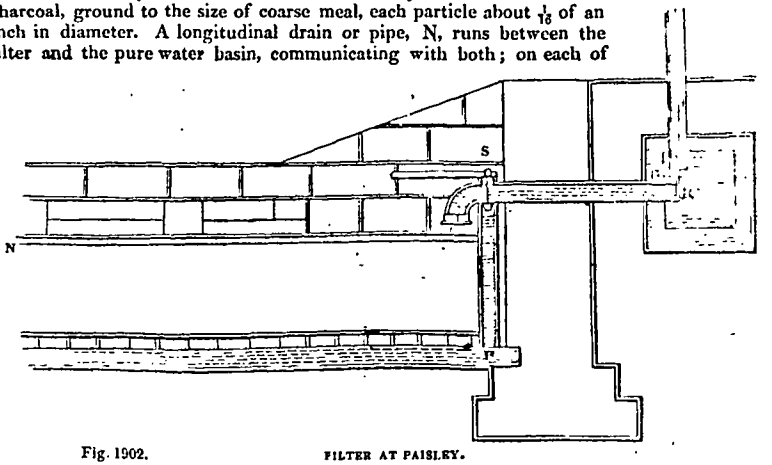


Fig. 1902. FILTER AT PAISLEY.

the openings between the pipe and the filter is a stop-cock to close the communication when necessary; there are also two drains, to carry off the foul water when the filters are being cleaned, and another to prevent the water from rising too high: when the filter is complete, its action is as follows: the sluice R and the valve S are opened, and the water permitted to flow through the filter into the drain N below, until it becomes quite clear. This will take two or three days when first set to work, unless very great pains are taken to wash the gravel and sand before they are put into the filter, which will now flow copiously for some weeks, and when the quantity passing begins to decrease, the stop-cocks are shut, and the valves S raised. The water then enters below, filling all the drains, and having a head pressure of several feet it will force its way up through the sand to the top, and in its passage raise the scales or particles of mud which have been

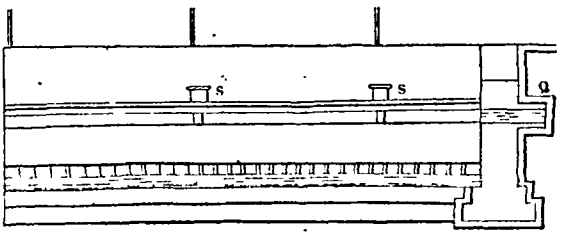


Fig. 1903. FILTER AT PAISLEY.

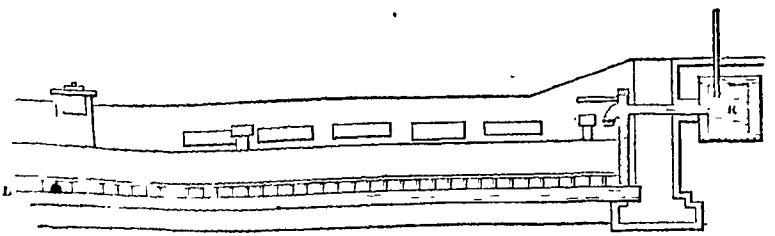


Fig. 1904. FILTER AT PAISLEY: SECTION OF SIDE.

deposited in the downward passage, and carry them into the foul water drain below. If the sand of the surface be stirred by a fine-toothed rake, after the water has been raised above it, and a little additional water admitted on the top, through the conduit, it will facilitate the operation of cleaning, as the mud is always deposited on the very surface of the sand.

By this means the sediment will be carried off, and the water pass through quite clear again in a few hours; the valves, S, should then be lowered, the stop-cocks opened, and the operation of filtering will again proceed as above described. The cost of this filter was 600 pounds, and the quantity of pure water produced regularly every 24 hours is on an average 106,632 cubic feet.

We have already described other methods which have been adopted by the several water companies for the purification of water, to which we must refer.

Cost of raising Water, as given to the Commissioners of Inquiry into the State of Large Towns by Thomas Wicksteed, the engineer to the East London Waterworks.

1st. A single pumping engine, made by Boulton and Watt in 1809, working 10½ hours per day, 6 days per week, mean power 29½ horses: quantity of water raised per day equal to 612,360 gallons 100 feet high: the cost of coal 12 shillings per ton; in the estimate, all charges, working the engine, coals, labour, and stores, are included, but none for interest upon outlay, or repairs of machinery and buildings.

	s.	d.
Cost of raising 1000 gallons 100 feet high	0	0·543
Or 22,099 gallons 100 feet high	1	0

This estimate is upon an average of two years' working.

2nd. Two single pumping engines, by Boulton and Watt in 1809, working 24 hours per day, 7 days per week, mean power of each engine 30½ horses; quantity of water raised per day, 2,922,480 gallons 90 feet high; the cost of coals 12s. per ton. Labour, horses, &c., taken as before. The estimate upon an average of 10 years' working.

	s.	d.
Cost of raising 1000 gallons 100 feet high	0	0·358
Or of raising 33,519 gallons 100 feet high	1	0

3rd. Two single pumping engines, made by Boulton and Watt, one in the year 1816, and the other in 1828, working 12 hours per day, 7 days per week, mean power of each engine 76 horses, quantity of water raised per day 3,601,116 gallons 100 feet high; cost of coals 12s. per ton. Labour, horses, &c. as before. The estimate upon an average of 10 years' working.

	s.	d.
Cost of raising 1000 gallons 100 feet high	0	0·333
Or of raising 36,036 gallons 100 feet high	1	0

4th. One single pumping engine made by Harvey and Co., upon the expansive principle, in the year 1837, working 24 hours per day, and 7 days per week, mean power 95½ horses; quantity of water raised per day 4,107,816 gallons 110 feet high; cost of coals, 12s. per ton; labour and stores as before; the estimate upon an average of four years' working.

	s.	d.
Cost of raising 1000 gallons 100 feet high	0	0·150
Or, of raising 80,000 gallons 100 feet high	1	0

The foregoing statements show a great variation in the cost of raising water with different engines. The comparison, however, is favourable to those on the old plan, and of the best make. The following table expresses the variation more clearly:—

To raise 160,000,000 gallons of water 100 feet high, it would cost,	£.
according to the first statement,	362
second ditto	238
third ditto	222
fourth ditto	100

A very great economy in the power employed in pumping water might be effected by the use of the expansive engine and plunger pump, the advantages of which have been acknowledged in the mines of Cornwall for more than thirty years: this principle, Mr. T. Wicksteed observes, was first introduced into waterworks in the year 1837, when an engine was set up at the East London Waterworks, and is now working most satisfactorily, having from the time of its first starting continued to raise 225 barrels of water, with the same quantity of coals required by the best engine on the works, made upon the old construction, to raise 100 barrels; since that time another large engine of the same description has been erected at the Southwark waterworks, which acts in an equally satisfactory manner.

There is also another advantage derived from the introduction of this new engine, namely, that the same quantity of water may be raised from 2½ to 5 times the height, by the consumption of a given quantity of coals; and as the size of the pipes depends upon the velocity of the water passing through them, and that velocity increases as the square root of the head of water, so by increasing that four times, the dimensions of the pipes may be reduced to one-half; the chief item in the expenditure in new works may consequently be reduced one-half, and less capital be required.

Sluice Cocks, for letting off the water of a reservoir into the mains, are of various kinds; the most ingenious are those by which the valve can be opened and shut at

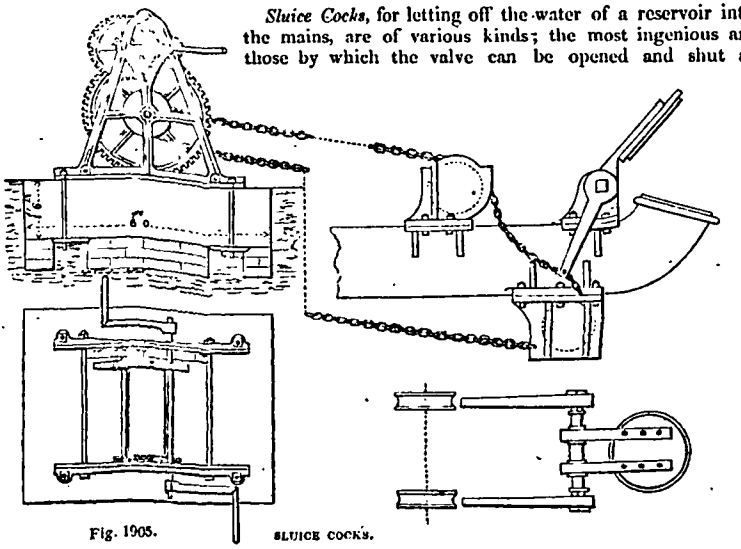


Fig. 1905. SLUICE COCKS.

pleasure by means of levers. The valve which covers the mouth of the discharging pipe has two arms secured to an iron axle, at the extremities of which are two levers; the chain fastened to one passes under, and the other over, a pulley, so that by turning a windlass either chain can be worked for the purpose of opening or shutting the valve.

The Screw is applied to the same purpose, that of shutting off the flow of water in the mains.

Laying down the Mains. The general rule according to Mr. T. Wicksteed to be followed, is "to take care that the distances between the mains shall not be too great, for if it be so it will be necessary to have services of larger diameter than would otherwise be required: to prevent loss in pressure occasioned by friction, the communications between the mains and services must be kept open for a longer time, to give a supply to those houses at the extremity of the service; for when water is forced through pipes, either by a natural or artificial head, or by steam or other power, friction is created in proportion to the velocity of

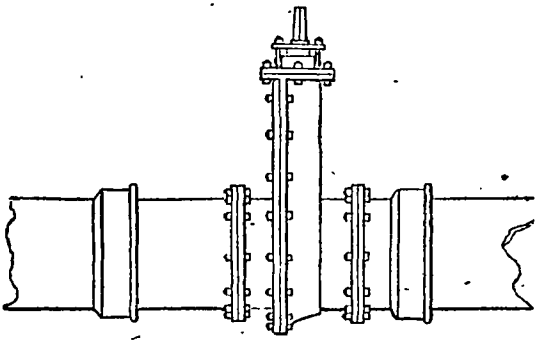


Fig. 1906.

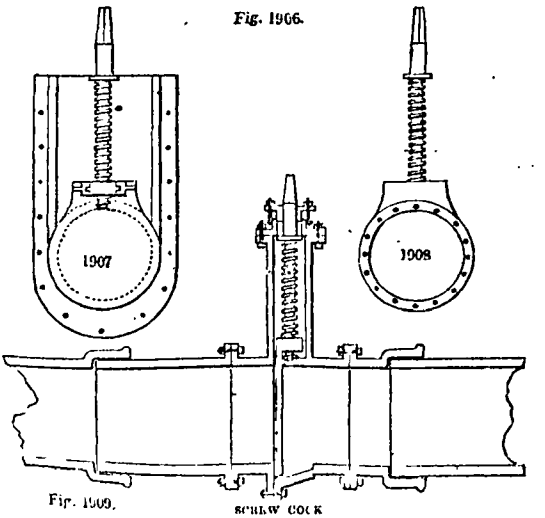


Fig. 1909. SCREW COCK

the water and length of the line of pipes: as the distance increases, the power must either be increased or the velocity reduced; the shorter the distance, the less the power required to overcome the friction; if it be therefore necessary to exert a great power to force the water to the extremities of an extensive district, that they may be properly supplied, it is very evident that the power exerted near the source, not being required to overcome so great an amount of friction as at the extremities, will increase the velocity of the water through the orifices near the source; consequently, therefore, if some arrangement were not made to prevent it, the houses so situated would have a superabundant supply, whilst those at a distance would obtain a very small quantity, if any: when, however, those near the source have received their supply, the cocks on the services are shut down, and the water in the mains will pass on to supply the extremities: that each may have an equal supply, those near the source have the communication opened with the main for a shorter time than those at a distance, in proportion to the velocity with which the water is delivered. In addition to this, on every line of mains and services, orifices about 2 inches in diameter are made at certain distances, filled up with fire-plugs, which get the whole force of the water simply by closing the service-cocks, in such a manner that in case of fire or other accident it may be concentrated at the spot required.

Supposing, then, water to be required for 20,000 houses, and the height to which it must be raised at the works is such that a 20-inch main would be sufficient to give the supply according to the foregoing system; it could not be so, if the water were constantly on in all the pipes, both mains and services; for if the size of the lead pipes to supply the houses be upon an average ½ inch in diameter, the aggregate areas of 20,000 half-inch pipes would be equal to 27½ square feet, and a main of 71 inches in diameter would be required at the source to supply the town instead of 20 inches, and for side streets, containing 100 houses each, pipes of 5 inches in diameter, instead of 3 or 4 inches: this is an extreme case, but one that it may be necessary to provide against, because if the water is always on, the houses may be all supplied at one time, and even, trusting to the chances of only one-half that number, the main must be 48 inches in diameter at the source. In addition to the necessity for this extraordinary outlay, in the first instance, the quantity of water used would be enormous; and consequently, the expense of raising a sufficient supply be increased in proportion, and the object sought, that of having a strong pressure of water in the mains, would be defeated by the very means proposed to insure it; for, as the water in the pipes would be always on, so would the draught by the houses be constant, and the present power of shutting off the supply from the side streets, and applying the full force to the particular locality requiring it, would be destroyed: again, if separate mains were laid from the works to be used as fire-mains only, the expense would be nearly the same as that of the system of pipes for supplying the inhabitants, and this item, which is the most important portion of the outlay in waterworks, would be nearly doubled.

Mr. T. Hawkesley, in his evidence taken before the Commissioners, states, that if the water for the supply of the metropolis were taken from the Thames, in its full purity, above Windsor, and filters or subsiding beds erected there, the transmission of 500 gallons of water per second might be effected by two mains, each of 60 inches in diameter. He calculates the resistance from friction from this formula for long pipes, $P = \frac{Q^2 l}{140 d^5}$, in which P represents the horse-power necessary to overcome the friction, l the length of the pipe in inches, Q the quantity of water to be delivered in one second, and d the diameter of the pipe. Hence it appears that the resistance arising from friction in pipes of the given size, and 25 miles long, would require less than 450 horse-power, beyond the force employed to raise the water into an elevated reservoir: if this reservoir were situated at a height of 220 feet, the steam power required to raise the water would be about 2000 nominal horses, and the total power in transmitting and raising 500 gallons per second would amount to less than 2500 horses. The cost of the main pipes would be about 1,000,000*l.* sterling; of the engines and machinery, with some reserve of power, about 150,000*l.*, and of the tanks and reservoirs probably 200,000*l.*

Height that a jet of water rose from the mains and services belonging to the Southwark Water Company, under a fixed pressure of 120 feet. The first trial was made in Union Street, between High Street and Gravel Lane, Borough, 31st January 1844, over an extent of 800 yards of 7-inch main, and through the Fire Brigade stand-pipes, hose, and jets. This 7-inch main is connected to the 9-inch main in the High Street, Borough, which, after a run of 500 yards, is joined to 200 yards of 12-inch main, and then continued by 550 yards of 15-inch main to the great main, leading from the company's works at Battersea, making a total distance of 5500 yards from the place where the experiment was made.

One	2½	inch stand-pipe, with	40	feet of hose, and	⅞	inch jet, rose	50 feet.
Two	2½	—	40	—	⅞	—	45
Three	2½	—	40	—	⅞	—	40

Four $2\frac{1}{2}$ inch stand-pipe, with 40 feet of hose, and $\frac{7}{8}$ inch jet, rose 35 feet.
Five $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 30
Six $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 27

All the fire-plugs on the main were then closed, except the first, and one $2\frac{1}{2}$-inch stand-pipe with 160 feet of hose and $\frac{7}{8}$-inch jet, rose 40 feet. The quantity of water delivered from the same main, through one stand-pipe, and different lengths of hose, was as follows, viz: —

One $2\frac{1}{2}$ inch pipe, 40 feet of hose, $\frac{7}{8}$ inch jet, delivered 96 gallons in 59 seconds.
$2\frac{1}{2}$ — 80 — $\frac{7}{8}$ — 112 — 65
$2\frac{1}{2}$ — 160 — $\frac{7}{8}$ — 116 — 70
$2\frac{1}{2}$ — 40 — $2\frac{1}{2}$ — 118 — 27

The second trial in Tooley Street, of a 9-inch main, 1400 yards in length, connected to 1000 yards of 15-inch, and 6650 yards from the works.

One $2\frac{1}{2}$ inch-stand pipe, 40 feet of hose, $\frac{7}{8}$ inch jet, rose 60 feet.
Two $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ difference not perceptible.
Four $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ rose 45 feet.
Six $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 40

Quantity delivered from the same main trough.

One $2\frac{1}{2}$ inch stand-pipe, 40 feet of hose, $\frac{7}{8}$ inch jet, 114 gallons in 64 seconds.
Four $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 115 — 75
Six $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 112 — 78

Four-inch service in Tooley Street, 200 yards long, supplied through 200 yards of 5-inch pipe, from 9-inch main, one $2\frac{1}{2}$-inch stand-pipe fixed on the 4-inch service, near the 5-inch pipe, with 40 feet of hose, $\frac{7}{8}$-inch jet, rose 40 feet. Two $2\frac{1}{2}$-inch stand-pipes, $\frac{7}{8}$-inch jets, rose 31 feet.

One $2\frac{1}{2}$-inch stand-pipe fixed at the end of service, 200 yards from 5-inch pipe, 40 feet of hose, $\frac{7}{8}$-inch jet, rose 34 feet.

Quantity delivered from the plug near the 5-inch main, through

One $2\frac{1}{2}$ inch stand-pipe, 40 feet of hose, $\frac{7}{8}$ inch jet, 112 gallons in 82 seconds.
Two $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 117 — 103

Quantity from end of plug of service 200 yards, from the 5-inch main.

One $2\frac{1}{2}$ inch stand-pipe, 40 feet of hose, $\frac{7}{8}$ inch jet, 112 gallons in 90 seconds.
Two $2\frac{1}{2}$ — 40 — $\frac{7}{8}$ — 114 — 118

It is also stated that water will rise higher from a hose attached to a fire-plug in the street, at the extreme point of the delivery, in the night than in the day-time, and that when water is in motion, there will be friction in the main pipes, by which the height to which it rises is diminished. The higher the water is thrown on a pipe, or the higher the nozzle of a hose-pipe is carried, the more the resistance of the atmosphere is avoided: if a jet acting under a pressure of 100 feet attained an elevation of 50 feet when discharged from the level of the pavement, and the hose pipe were elevated to the height of 50 feet, a jet would be given probably from 20 to 25 feet in height: by this means, the water would attain an elevation of 70 or 75 feet, instead of 50; hence the advantage of carrying a hose-pipe up stairs or on a ladder, or as nearly as possible to the height of the story, when a fire occurs.

CHAP. XIX.

ATMOSPHERE AS A MOVING POWER.

In the year 1667 Dr. Croune laid before the Royal Society the first instrument contrived for measuring the force of the wind; consisting of a fan included within a cylindrical vessel, which was divided into 32 equal parts, each having a narrow slit, through which the air might pass: this imperfect machine was afterwards improved by Dr. Hooke, and others, and several very ingenious anemometers are now made use of, by which both the force and velocity of the wind may be ascertained. The weight or pressure of the atmosphere is shown by the sucking pump, sustaining a column of water, or the barometer by a column of mercury which is exactly equal in weight to a cylinder of air of equal diameter, reaching to the top of the atmosphere. The mean height of the barometer at the level of the sea is about 28·6 inches, and 1 cubic inch of mercury weighs 3425·92 grains, or 0·48956 pounds avoirdupois; so that a column of mercury whose base is a square inch, and having the mean height of the barometer, weighs $0{\cdot}48956 \times 28{\cdot}6 = 14{\cdot}6$ lbs. avoirdupois, which is

the weight of the atmosphere on every square inch of the earth's surface. The height of the atmosphere has been estimated at 328,021 inches, or 5·17 miles.

The elasticity of the air having been ascertained by the experiments of Boyle, it was not difficult to construct the air-pump, though the one used by this celebrated philosopher was inconvenient for many purposes, in consequence of the necessity of alternately opening and shutting the stop-cock and valve, and the difficulty of making the piston descend when the air within the pump was greatly rarefied.

Hawksbee and Smeaton both turned their attention to its improvement: the latter found considerable difficulty in opening the valves at the bottom of the barrels, and from the pistons not fitting exactly when put close down to the bottom, leaving a lodgment of air that could not be pumped out of the barrel. The first of these defects arose from the small orifice through which the air passed on raising the bladder, which opposed a considerable resistance, from the necessity of keeping it moist with oil. To remedy this Mr. Smeaton resolved to expose a greater surface to the action of the air; with this view, instead of one hole he used seven, all of equal size and shape, one being in the centre, and the other six round it, so that the valve was supported at proper distances by a kind of grating formed by the solid parts between these holes, which were hexagonal, and the partitions filed almost to an edge; the metal was made a little protuberant, to prevent the piston from striking against the bladder. To prevent any lodgment of air in the lower part of the barrel, he removed the external pressure from the piston-valve, by making the piston move through a collar of leather, and forced the air out by a valve applied to the plate at the top of the barrel, which opened outwards.

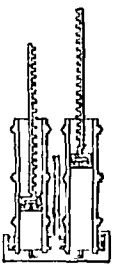


Fig. 1910. HAWKSBEE'S AIR-PUMP.

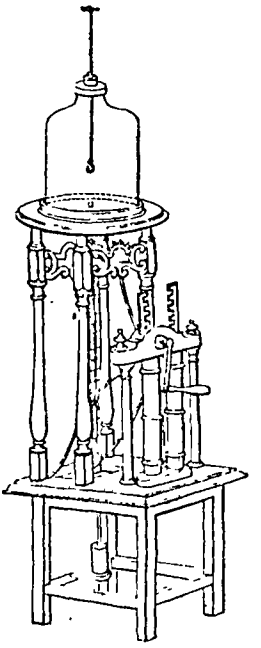


Fig. 1911.

Cuthbertson, of Amsterdam, considerably improved Smeaton's air-pump, by allowing the air to escape by opening a passage to it mechanically, without the assistance of its elastic force.

The construction of the air-pump is very simple, the essential part consisting in the exhausting syringe, a brass tube closed at one end, with the exception of a small orifice, to which a valve opening inwards is attached; an air-tight piston is worked up and down on the barrel by a rack and pinion turned by a winch. The piston has also an orifice, with a valve, which opens upwards, or in the same direction as the valve of the tube. The syringe communicates by means of a small pipe fitted into the opening at its lower extremity, with a vessel called the *receiver*, from which the air is to be pumped out. The two exhausting barrels are worked by a rack and pinion, so that one piston ascends while the other descends, and attached to the pump

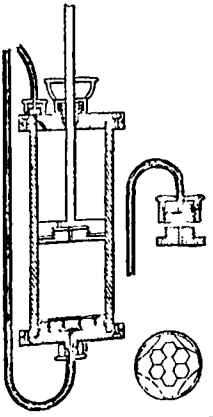
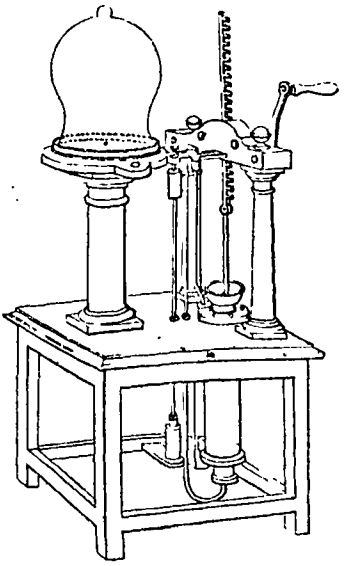


Fig. 1912.



SMEATON'S AIR-PUMP. Fig. 1913.

is a barometrical gauge or tube 6 or 8 inches in length, sealed at one end and filled with mercury; as soon as the tension of the contained air becomes less than sufficient to support the column of mercury, the liquid begins to fall, and the height at which it stands above the level of that, on the basin into which it is plunged, is the measure of the tension of the remaining air.

On the subject of the *winds* much has been written, but the various theories are involved in considerable obscurity; its velocity varies from zero up to 100 miles an hour.

Post Windmills are much in use in many parts of England for grinding corn or cement, but their size being limited, they are not generally applied to drive machinery for other purposes. The mill is usually made on a rectangular plan, and the narrow side turned to the wind. The wind-shaft bearing on a beam at each end has a little inclination, and on the outside is increased in dimension, forming a square for the better mortising the whips or arms of the sails, which are wedged tightly into it. The inclined wheel attached to the wind-shaft has on its circumference a rim of wood, called the brake, one end of which is fixed to the side of the mill, and the other, by an iron rod, to a lever, which can be pressed down, and made to bind upon the circumference of the wheel, with sufficient power to stop the mill. The whole mill revolves round the upright post in the centre, which is framed at bottom into some long horizontal timbers secured to the ground, from which four oblique braces are strutted, to maintain it in its vertical position. Where this upright post passes, the floor of the mill is a circular iron collar, and at the upper end of the post is a pivot or gudgeon, entering a socket, let into one of the timbers, made of considerable strength, as the entire weight of the mill rests upon it. The mill thus balanced is turned by the ladder which serves as a lever; after the right position is obtained, it is kept steady by dropping the ladder on the ground; this is readily performed by a rope and pulley, or by manual labour.

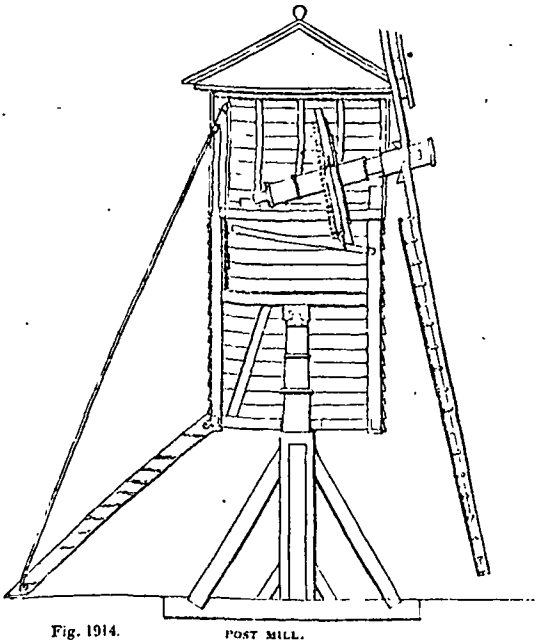


Fig. 1914. POST MILL.

The Tower or Smock Mill was formerly more common, but since the general introduction of the steam-engine it has gone out of use in many districts. The body of the mill is constructed either in brick or stone, and sometimes of timber; at the top of the building a wooden curb is laid, or strong wall plate, on which the rollers of the cap revolve, and it is essentially necessary that this portion of the work should be rendered very secure, or the rattle and motion of the machinery will loosen and derange it, or cause great inconvenience.

In the outer end of the wind-shaft, which is commonly made of iron, are cast two sockets for the insertion of the whips of the sails, which are tightened in their place by wooden wedges. The pillows which bear the wind-shaft are of brass, and sometimes of hard stone. The driving or brake wheel is bevelled, and furnished with two rows of teeth, which act alternately upon those on the bevelled crown wheel, on the top of the upright shaft, and by this arrangement a more regular motion is obtained: these *hit and miss* wheels, common in many parts of England, are admirably adapted to windmills.

The brake wheel has a wooden rim, one end of which is attached to the framing of the mill and the other to a lever: a rope passing over a pulley to the outside of the mill enables the miller to raise the end of the lever, and engage it with a hook, which liberates the brake, and allows the head of the mill to move freely round: when it is required to stop the mill by pulling the rope, the end of the lever is disengaged from the hook, which falling on the brake brings it down upon the wheel, and stops all motion even during the

highest winds. The plan of the head is extremely simple, and requires to be merely balanced.

The self-adjusting Cap is turned round by the force of the wind, which acts upon a flyer or fan, so contrived that it always presents the sails in the proper direction, by means of a smaller pair attached to a gallery projecting from the back of the cap; on the axle of this fan is a pinion engaging in another wheel attached to the inclined axis, at the other end of which is fixed a bevelled pinion working a wheel on the vertical spindle of another pinion, which is engaged in the cogs, arranged round the outside of the fixed curb, so that when the flyers are turned, the head of the mill is slowly turned round, the power depending upon the ratio of the several radii. Care must be taken that its action be sufficient to make a change when sudden gales arise, as

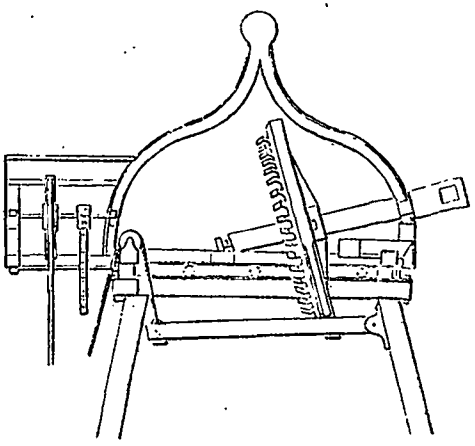


Fig. 1915. SELF-ADJUSTING CAP.

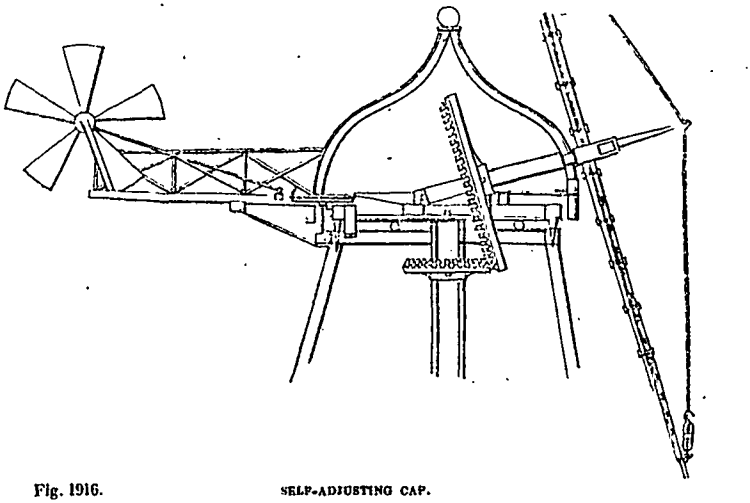


Fig. 1916. SELF-ADJUSTING CAP.

it has frequently occurred, where these self-acting caps have been introduced, that if the brake had not been made use of in time to turn the sails rapidly, the mill would have fired.

The sails of windmills are of various kinds, and the fixing them requires great skill on the part of the millwright. When the shafts are of cast-iron, they have at their extremities two sockets to receive the arms, also of the same metal; these, after being inserted, are further secured by two pieces of timber,

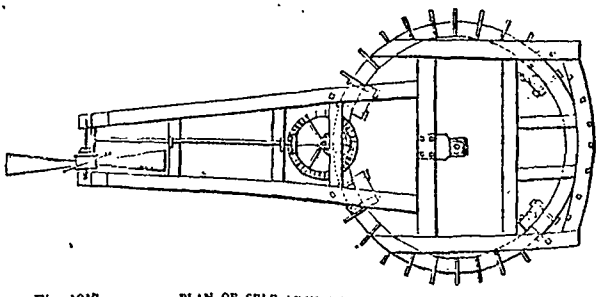


Fig. 1917. PLAN OF SELF-ADJUSTING CAP.

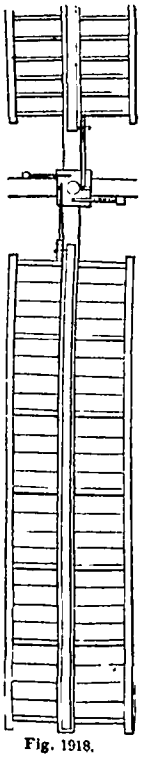


Fig. 1918.

which cross and continue up the back of each arm, to which they are firmly screwed; by these timber horns, as they are called, the whole is very much strengthened.

The whips are generally placed at right angles to each other, and when 40 feet in length their scantling is about 10 inches by 8, or 10 inches square: at ¼ of the length of the arm from the centre of the wind-shaft is the first bar, which is inserted to make an angle of 60 degrees with the axis of the wind-shaft: 20 other bars are then placed at regular and equal distances to the end, each making 1 degree of the angle less, so that the last bar at the end has only an angle of 20 degrees; the bars are all of the same length, generally 5 feet.

The length of the sails of the Dutch mills is not more than 33 feet, and their width about 6, 5 feet being covered with cloth, and the other

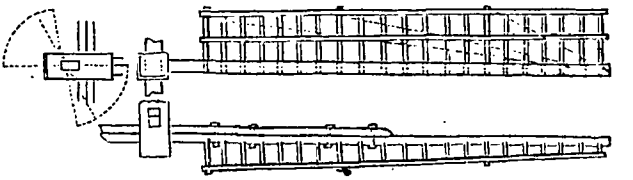


Fig. 1919.

part boarded; where the board and cloth unite, a curve is formed, which gradually diminishes towards the end, and the angles formed by the tangents of this curve and the plane of their motion is called the angle of weather, which at the foot bar is 30 degrees, gradually diminishing to 12 degrees.

In 1772 Mr. Andrew Mickle contrived a method by which the sails of a windmill could adjust themselves; but that patented in 1804 by Mr. John Bywater, of Nottingham, was the most efficient; it consisted in rolling or folding up the sails to the whip, by means

Fig. 1921.

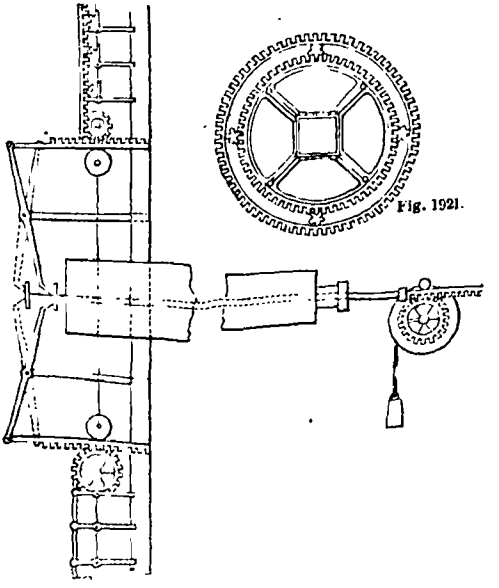


Fig. 1920. BYWATER'S SELF-ADJUSTING WINDMILL.

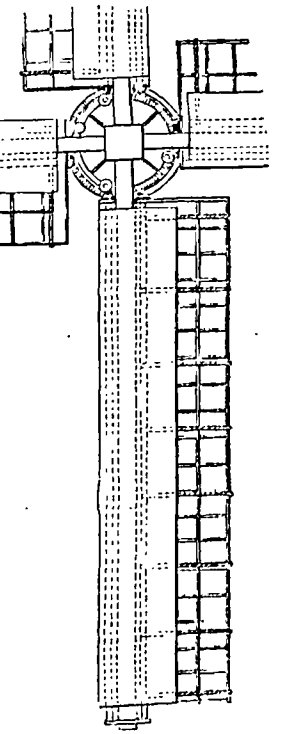


Fig. 1922.

of cylinders which extended the whole length of the sails, and were put in motion by a system of wheelwork connected with the shaft in the following manner:—a ring of iron about 4 inches wide and ¾ of an inch thick, was attached to the main-shaft, and concentric with it, a short distance behind the whip: a bevelled wheel without arms is made to revolve easily upon the circumference of the ring, and a spur-wheel without arms turns upon four pins in the back of the same. The whole machinery revolves with the shaft, and when the quantity of canvas spread is too great, a lever fastened to the bracings, and weighed so as to hang vertically, is brought into a horizontal position by means of a string attached to the end within the mill; in this position it engages a stud upon the spur-wheel, and prevents its motion: a bevelled wheel then gives motion to the four small pinions, and with them the cylinders, which continue to wind up the cloth, until the miller from within lets go the string, and the lever is disengaged from the stud.

On the relative Effects of Windmill Sails, according to Smeaton and Coulomb.—The velocity of windmill sails, whether unloaded or loaded, producing a maximum effect, is nearly as the velocity of the wind, their shape and position being similar. The load at the maximum is somewhat less than as the square of the velocity of the wind, the shape and position of the sails being the same. The effects of the same sails at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind. The load of the same sails at the maximum is nearly as the squares, and their effects as the cubes of the numbers of turns in a given time: when sails are loaded, so as to produce a maximum effect at a given velocity, and the velocity of the wind increases, the load continuing the same, the increase of effect, when that of the velocity of the wind is small, will be nearly as the squares of those velocities: when the velocity of the wind is double, the effects will be nearly as 10 to 27½: when the velocities compared are more than double that where the given load produces a maximum, the effects increase nearly in the simple ratio of the velocity of the wind. In sails where the figures and positions are similar, and the velocity of the wind the same, the number of turns in a given time will be reciprocally as the radius or length of the sail: the load at a maximum overcome by sails of a similar figure and position, at a given distance from the centre of motion, will be as the cube of the radius.

The effects of sails of similar figure and position are as the squares of the radius: the velocities of the extremities of Dutch sails, as well as of the enlarged sails, in all their usual positions when unloaded, or even loaded to a maximum, are considerably quicker than the velocity of the wind.

Number of Ale Gallons delivered on an Overshot Wheel 10 ft. in diameter every minute.	Diameter of the Cylinders of the common Steam Engine in inches.	Diameter of the Cylinder of the Improved Steam Engine in inches.	Number of Horses employed 9½ working hrs. per day, and moving at the rate of 2 miles per hour.	Number of men working 12 hours per day.	Radius of Dutch Sails in their common position in feet.	Radius of Dutch Sails in their best position in feet.	Radius of Mr. Smeaton's enlarged Sails in feet.	Height to which these different powers will raise 1000 lbs. avoirdupois in a minute.
230	8·	6·12	1	5	21·24	17·89	15·65	13
390	9·5	7·8	2	10	30 04	25·30	22·13	26
528	10·5	8·2	3	15	36·80	30·98	27·11	39
660	11·5	8·8	4	20	42·48	35·78	31·30	52
790	12·5	9·35	5	25	47·50	40·00	35·00	65
970	14·0	10·55	6	30	52·03	43·82	38·34	78
1170	15·4	11·75	7	35	56·90	47·33	41·41	90
1350	16·8	12·8	8	40	60·09	50·60	44·27	104
1445	17·3	13·6	9	45	63·73	53·66	46·96	117
1584	18·5	14·2	10	50	67·17	56·57	49·50	130
1740	19·4	14·8	11	55	70·46	59·33	51·91	143
1900	20·2	15·2	12	60	73·59	61·97	54·22	156
2100	21·0	16·2	13	65	76·59	64 5	56·43	169
2300	22·0	17·0	14	70	79·49	66·94	58·57	182
2500	23·1	17·8	15	75	82·27	69·28	60·62	195
2686	23·9	18·3	16	80	84·97	71·55	62·61	208
2870	24·7	19 0	17	85	87·07	73·32	64·16	221
3055	25·5	19·6	18	90	90·13	75·90	67·41	234
3240	26·2	20·1	19	95	92·60	77·98	68·23	247
3240	27·0	20·7	20	100	95·00	80·00	70·00	260
3750	28·5	22·2	22	110	99·64	83·90	73·42	286
4000	29·8	23·0	24	120	104·06	87·63	76·68	312
4460	31·1	23·9	26	130	108·32	91·22	79·81	338
4850	32·4	24·7	28	140	112·20	94·66	82·82	364
5250	33·6	25·5	30	150	116·35	97·98	85·73	390

Comparisons of the Effects of Mechanical Agents. — A horse raising coals, by means of a wheel and axle, moving at the rate of 2 miles per hour, and working 9½ hours per day, raised 1000 pounds avoirdupois to the height of 13 feet per minute: an overshot water-wheel, 10 feet in diameter, and served by 230 ale gallons of water per minute, a steam-engine with an 8-inch cylinder, and an improved one 6·12 inches in diameter, will do the same work as a horse; upon which data the preceding table has been constructed.

Of Blowers and Ventilators. — There are several kinds of blowers, differing from each other principally in the flexibility or inflexibility of their sides: a sack of leather or other substance, which is flexible and impermeable to the air, being filled with this fluid and compressed, would experience a pressure from the interior to the exterior, and if a tube open at both ends were attached to it, the air would be compressed in the tube, and would rush out with a velocity due to its elastic force.

The regularity of the blast which maintains the combustion of furnaces is of the greatest importance in the success of metallurgic operations, and to obtain this it is requisite that the air-reservoir should be of such dimensions that the air which leaves the tube at each stroke of the blower should be compressed into a very small volume with regard to the capacity of the reservoir. The blower used at the Carron furnace is built of stone and vaulted; its internal capacity is 445 cube metres; the air which rushes out at each stroke of the piston is to the atmospheric pressure only as the 84th part of this capacity.

Whatever be the form of a blowing machine, the first points to be considered are the pressure of the air in the reservoir, the volume which escapes through the pipe at each stroke of the piston, and the number of strokes in a given time. The volume of the air which passes in a unit of time, 1 second for example, from the pipe into the furnace being determined, and divided by the area of the orifice of the tube, will give the velocity of the blast at the orifice. The greatest pressure of the air in the reservoir rarely exceeds the weight of a column of water 3 metres high, and may be measured by a column of mercury 13 or 14 times less, the 3 metres of water answering to 22 centimetres of mercury: if we multiply the number of cube metres of air in the reservoir, which escapes through the tube in a given time, an hour for example, by the height of the column of mercury, and by the density, 13·6, of this liquid, the product of the three quantities will express in units, each of one cube metre of water raised 1 metre, the dynamic effect which the blowing machine would produce in an hour. The moving power applied to the bellows will, at the same time, be capable of a greater effect, since it will have to overcome the inertia and friction of the movable parts of the blowing machine: if we measure the pressure of the air in the reservoir by a column of water, the height of this column, and the volume of air issuing from the reservoir, will be the two factors of the product which measures the dynamic effect of the blower. The object of ventilators is to renew the air in a given place, or rather to produce an artificial wind, by transporting the air from one space to another. These two spaces communicate by a cylindrical tube, the extremity of which is fixed in the centre of a drum, formed by two circular parallel plates, and united by supports in the circumference of these plates. A fly with 6 or 8 vanes turns in the interior of the drum; the air being driven from this is replaced by that in the cylinder, whence it follows that it must be elevated from one extremity of the cylinder to the other, which communicates with the drum: by placing a ventilator in a chest closed on all sides, and divided into two compartments, the air in the chest receives such a motion that it continually passes and repasses from one compartment to another; if, in the same chest, such substances as sulphur, charcoal, and saltpetre are reduced to powder, the air will carry with it the finer particles, and separate them from those not sufficiently pulverised. The quantity of air to be raised from one place to another being given, the relation of the dimensions of the parts composing the ventilator can be established, and the moving power required estimated. Ventilators are used to renew the air in low close places, such as pits, mines, cisterns, holds of ships, also in powder-mills to dry the powder in winter by currents of warm air; it has also been proposed to employ them to assist the evaporation of the water contained in various preparations made from sugar, as syrup, &c. In the south of France, a single cube metre of air, placed in contact with water, will evaporate three grammes: thus knowing the number of cube metres which a ventilator can put in contact with water in a given time, the quantity vaporised in the same time can be estimated. In coal-mines a portion of the small coal reduced to powder, and of little value in commerce, is used to maintain fires in the upper part of vertical shafts, which communicate with the galleries, where the warm air rises and is replaced by the lower air, which causes a current in the interior of the galleries, towards the top of the shafts: if in the interior of the shafts a horizontal axle were placed, carrying a fly, it is evident that the current of hot air would turn the axle: by a similar method, in some kitchens, the hot air which rises in the chimney serves as a mover to a smoke-jack.

We have considered air as a mover, and as a body to be moved: there is another point of view in which we must regard it, as a resisting medium. We know that a body projected into the air soon loses its initial velocity: the air at rest, struck by a body, first is

compressed, and then passes into a more or less compounded state of motion. Birds using their wings as oars in the water find in the air a fulcrum to raise themselves by; they owe this faculty of flying to a muscular force which, compared to their mass, is superior to that of all other animals.

Parachutes in unfolding embrace a large volume of air, compress it, and communicate motion to it: the initial velocity due to weight decreases rapidly, and a mass of from 80 to 100 kilogrammes fixed to a parachute is soon reduced to that of a light body, such as a feather, which floats by itself in calm air.

The vanes on the fly of a turnspit experience, when turning in the air, a resistance which equalises the accelerating force of the moving weight, and by this means we regulate the motion of the endless chain which supports the spit; this regulator is also used in block-making. The effects of the air's resistance have been observed with care by philosophers studying gunnery: we shall show the results of their experiments when treating of gases employed as prime movers.

CHAP. XX.

WARMING AND LIGHTING.

Warming an Apartment.— We have already seen that, among the Romans, air was heated by passing over a small fire, and being then introduced into square earthenware tubes, which were made to circulate around the walls of their houses; these tubes, after heating the walls, by their radiating effect, raised the temperature of the rooms, or allowed the air so rarefied to pass from apertures in the pipes into the apartments, thus diffusing a warmth throughout: many of their villas discovered in England show the subterraneous furnaces, and we have no instance of the open fireplace much earlier than in the keep of Coningburgh Castle, built soon after the Conquest, the mantels of which are formed of flat arches, very ingeniously built, and bearing some resemblance to others constructed at an earlier period in the south of France.

Radiation, or the properties of heat, does not seem to have been understood, as applied to furnaces, till the end of the last century, when Count Rumford drew attention to the subject: the open fire was preferred in Britain at a very early period, and has continued to be so up to the present day, notwithstanding the waste of fuel and expense attending it. In the first cabins, and the halls of the Norman barons, the fire was made on a hearth in the centre of the hut or place to be warmed, the smoke generally finding its way through a hole in the roof, examples of which were remaining till lately at Penshurst Castle and other ancient houses.

The blazing hearth, like our open fires, contributed its heat by radiation, and it is well known that bodies will throw off heat when their temperature is far below that required for ignition. Scheele, in a work published about 1777, observed that radiant heat passed through air without communicating warmth to it, and that currents of air do not intercept it: before heat can be radiated, it must be absorbed, and rough, unmetallic substances, such as brick, are admirably adapted for this purpose: the heat which passes from an open fire radiates from the burning coal, as well as from the surfaces surrounding it; this traverses the air, and warms the bodies upon which it impinges; thus the contents of an apartment, all the furniture, which can absorb heat, so receive it, and again radiate it upon other bodies colder than themselves.

Various substances possess different powers of radiation, and those which are good radiators when hot absorb it quickly when cold: from Mr. Leslie's experiments, taking lampblack as equal to 100, crown glass is 90, plumbago 75, clean lead 19, and the polished metals from 12 to 15, proving that polished metals are bad radiators, and not such good recipients of heat as those surfaces which are not metallic. Sir Humphry Davy says "that vessels intended to retain their heat should be metallic and highly polished upon scientific principles, independently of elegance and delicacy. Steam or air-pipes for warming houses should be polished in those parts where the heat is not required to be communicated, and covered with some radiating substance, such as lampblack, wherever it is to be diffused. Culinary implements should be blackened, and not polished, on those parts which are to receive the heat: the surfaces of fireplaces or stoves should not be metallic, but of stony or earthy materials, which will communicate much more heat by radiation. The sun and an open fire both communicate heat upon this principle, and the worst conductors, as lampblack, ground glass, &c. are often the best radiators.

Heat which radiates in right lines is also susceptible of being reflected: if a cannon ball made red-hot be placed in the focus of one mirror, and an air thermometer in another,

the rays of heat which impinge on one are reflected, consistently with the property of concave mirrors, in parallel lines, so as to fall upon the opposed mirror, whence they converge to its focus, in which is the thermometer, and which will be affected proportionably to the heat of the original radiating body. As an experiment on the receptive and emissive powers of surfaces, in regard to radiant heat, it has been proved, that when two vessels filled with water are placed before a fire, the one clean and polished, the other coated with lampblack, the former receives the heat more slowly, whilst the latter cools more quickly.

In an open fireplace the fuel should be arranged as near the hearth as possible, in order that the air in the lower part of the room may become warmed; and the proportion given to the length of the bars which contain the coal should be equal to the twelfth part of the length of the room, if it be lofty and of good proportions; in their construction Stourbridge brick, or Welsh lumps, should be made use of in preference to metal, as they are far better radiators of heat, and less liable to destruction by too rapid expansion or contraction. Whenever coke can be used, the heat produced is far more agreeable, and there is no soot to lodge in the chimney: soft burnt coke, broken into small pieces, when all the gases have been abstracted, is far preferable in point of economy, and when the method of lighting and maintaining its combustion is acquired, coal is seldom again resorted to. Attention is requisite to prevent too rapid a draught up the chimney, otherwise the greater portion of heat will be drawn up it, and pass off without warming the room. The chimney which is said to draw well, consumes well, and is by no means always the best; that which draws sufficiently only, is the most economical in its consumption: all that need be desired is to pass off the smoke, or prevent the cold air from descending down the shaft, and disturbing the process of combustion, forcing the dust and smoke into the apartment: different states of the atmosphere require different areas of flue; when the air is very heavy, it often descends in our ordinary chimney more rapidly than it can become rarefied; and the column of warm air, ascending cylindrically in a square flue, the four angles are so many passages for the descent of cold airs; the less these disturbing forces occur, the less chance is there of a smoky chimney.

Grates or Stoves, which have an open fire, and an apparatus for throwing out a stream of warm air, are much used: this is effected by passing the air received by a pipe from the outside of the building through a double casing, which surrounds the fuel in the grate; in many parts of France, where wood is burnt upon the hearth, the back of the fireplace is hollow, or has a chamber cast in it: by means of a pipe from the outside air is introduced to be warmed, which by another pipe enters at the skirting, or some other convenient part of the room.

The great quantity of hot air which passes up the chimney of an open fireplace has led to the adoption of close stoves in this country, and necessarily to various methods for insuring perfect ventilation; on the Continent they are universal, generally of earthenware, either round or square, and so placed as to warm the air before it is admitted into the apartment; in most of them the object seems to be, and a most judicious one, to produce a large volume moderately heated, rather than a small quantity of very hot air, the latter being apt to char or burn the organic dust which exists in the atmosphere of our apartments, producing an unpleasant smell: an artificial hypocaustum is an arrangement preferred in France; the small pillars which stand in the midst of the burning embers, and support the oven or chamber above, are hollow; through these the cold air from below ascends, and in its passage through the heated metallic supports becomes warmed before it enters the chamber, where, on its arrival, it is heated, and then by its expansion passes off by pipes, or ornamental apertures, where required.

Metallic Stoves, lined with fire-brick, are now generally substituted; they are found to assist in radiating as well, care being taken so to dispose the lining that the outer case shall never become red-hot, and only a sufficient quantity of air be admitted to feed combustion, without exciting a rapid draught and a great consumption of fuel. All bodies have the faculty of absorbing and emitting heat, so that radiation takes place, not only at the surfaces, but also in the interior of solids and liquids, in the same manner as in air: indeed the molecules of all bodies are regarded as so many foci radiating heat, and continuing to do so until the objects near them have arrived at the same degree of temperature: in solids as well as liquids the absorption takes place at very small distances, in air and in gases at very considerable distances.

The low Temperature, or Dr. Arnott's Stove, by means of an ingenious contrivance, economises fuel, and gives out a considerable degree of heat: it is a much more scientific arrangement than that practised in the ordinary close stove: only sufficient air is admitted to keep up a slow combustion, and the heat is communicated to the radiating surface of the stove; the air is admitted by means of a self-acting valve, opened or shut by the rise and fall of a thermometer, and the heat is prevented from passing into the chimney in consequence of the very gentle motion imparted to it by the small draught maintained.

To determine the quantity of surface of steam-pipes, or vessel necessary to warm a room in winter when the external temperature is 10° below freezing, and to make the apartment

of an agreeable temperature of 60°, there must be a surface of steam-pipe, or other steam-vessel, heated to 200°, about a foot square for every 6 feet of glass, as much for every 120 feet of wall, roof, or ceiling, and also for every 6 cubic feet of hot air escaping per minute, as ventilation: an ordinary sized window permits about 80 cube feet of air to pass through it in a minute, and there should be 3 feet of air per minute allowed for the respiration of each person in the room. According to Dr. Arnott's view the quantity of steam pipe for a room 16 feet square and 12 feet high, with 2 double windows, each 7 feet by 3, and with ventilation by them at the rate of 16 cubic feet per minute, would require 20 superficial feet, or 20 feet of pipe 4 inches in diameter, or a box 18 inches square and 2 feet high. A surface when heated, and exposed to colder air, gives out heat with a rapidity nearly in proportion to the excess of its temperature above that of the surrounding air, less than half the heat being given out by radiation, and more than half by the contact of the air: a foot of pipe of 200° external temperature in the air of a room at 60°, the difference being 140°, gives out nearly seven times as much heat in a minute as when its temperature falls to 80°, reducing the excess to 20°, or a seventh of what it was. The quantity of heat which changes the temperature of a cubic foot of water produces the same effect on 2850 cubic feet of atmospheric air.

Hot-water Apparatus for warming manufactories or large buildings, &c., which keeps up a circulation of hot water through iron pipes, the hot water having a tendency to rise, and as it cools to descend.

In France the hydraulic calorifère was thus described some years ago: the boiler was said to resemble the human heart, and the pipes which carried out and brought back the water, the veins and arteries. In the early application of this method, the fireplace was made in the middle of a large boiler, and from the top issued an ascending pipe, which mounted to a large cistern filled with water, from the bottom of which was another pipe that took the cold water into the bottom of the boiler. The rarefaction produced by the heat in the ascending pipe caused the cold water to descend from the pressure exercised upon it, and thus a regular circulation was maintained.

Hot-water apparatus is now made in a variety of forms: the most simple are those where one pipe, of 2 or 3 inches diameter, is made to surround a small room, or where two or more of such pipes are made use of. There are other arrangements where a number of small tubes are preferred; but in all the water is made to circulate through them upon the same principle: one of its earliest applications in England was, perhaps, at Bromley, in Kent, where the Marquis of Chabannes, in 1816, warmed the conservatory for Sir Samuel Scott, Bart., though it has been asserted that Mr. Watt warmed buildings in this manner as early as 1784.

M. Bonnemain, of Paris, who was decidedly the inventor, about 1777, had a calorifère, by which hot water circulated, and a regulator being attached to it, he could maintain so equable a temperature that he was enabled to hatch eggs, and produce a great many chickens; the variation being scarcely ever more than half a degree of Reaumur's thermometer. The regulator made use of depended on the unequal dilatation of different metals: a rod of iron, screwed to another of brass, was enclosed within a tube of lead, terminating at its upper end in a ring of brass: the leaden tube was plunged into the water contained in the calorifère, by the side of one of the circulating tubes; the dilatation of lead being greater than that of iron, at an equal degree of temperature, and the rod being also enclosed within the tube, it was heated much less than the tube; when the temperature was raised to the degree required, the lengthening of the tube brought the ring into contact with a claw, at the short end of the bent lever, and when the slightest increase of heat further lengthened the tube, the ring raised the claw of the lever, and allowed the other to descend: by this contrivance a wire was made to open or shut a valve, through which air was admitted to the fire, and the combustion either increased or lessened.

Various improvements have been made in the mode of warming by hot water: at first the pipes were cylindrical, and laid horizontally, but it being found that its motion was accelerated when placed in the two legs of a siphon, they are now laid in an inclined position, and flat

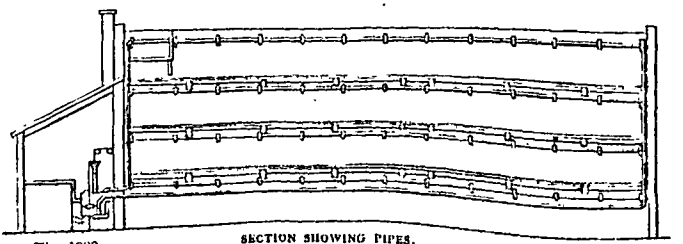


Fig. 1923. SECTION SHOWING PIPES.

iron pipes are substituted for the round, those giving out more heat: hermetically closed tubes are found useful in conveying the warm water to a greater distance; and then a smaller diameter of tube may be adopted, as the water may be raised to a temperature considerably above the boiling point: by the use of ascending and descending pipes, water may be made to circulate to any height; and it is calculated that a fire-grate of about 12 superficial feet, with a properly constructed boiler, consuming a bushel of coals per hour, is sufficient to heat a moderate dwelling; the boiler having a bottom surface, in this instance, of 48 feet, or four times the area of the grate, and about 32 feet of side flue. The quantity of pipe to be heated must regulate the size of the boiler, and as each cubic foot of water evaporated per hour requires 4 superficial feet, we may ascertain the requisite proportions for a boiler of a hot-water apparatus. Supposing the latent heat of steam 1000°, we shall find that the size of a boiler which would evaporate a cube foot of water, at the temperature of 52°, into steam, would supply sufficient heat to 232 feet of 4-inch pipe, and maintain its temperature 140° above that of the surrounding atmosphere.

When the difference between the temperature of the pipe and the air is 125°, it has been found that a foot of 4-inch pipe will heat 200 cubic feet of air 1° per minute; and when the pipes are 146° hotter than the air around them, the water within them loses 1° of heat per minute.

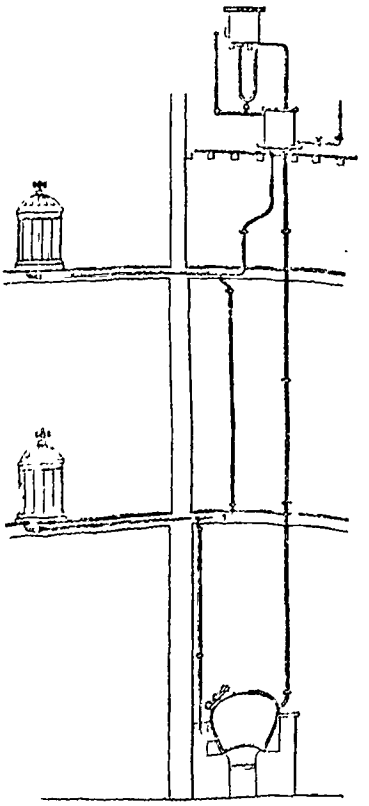


Fig. 1924. SECTION.

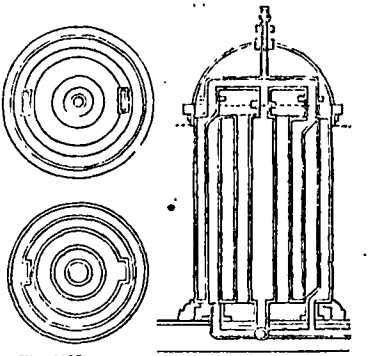


Fig. 1925. SECTION OF CALORIFERE.

Where many stories of a building are to be warmed the boiler and furnace are placed on

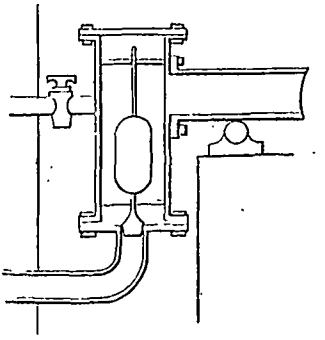


Fig. 1926. VALVES.

the lower story or basement, from which rises a flow-pipe to a warm-water-box placed at the top of the house; from this another pipe supplies a small calorifère or metal box containing water, one of which is placed in every room intended to be warmed: and after passing through all, the water returns to the boiler to be again heated; a regular circulation is thus kept up; the cold water, being heavier than that warmed, falls to the bottom of the pipe, and forces up the latter.

Each 100 feet of 4-inch pipe, containing 544 pounds of water, will require 14 pounds

of coal to raise its temperature throughout to 180°; and as the water loses only 60° of heat per hour, this quantity of coal will serve for 3 hours; 200 cubic feet of air being heated 1° per minute by every foot of 4-inch pipe, we must cube the contents of the building to be warmed, and divide it by 200, to obtain the number of feet of 4-inch pipe that shall have a temperature of from 55° to 56°; when greater heat is required, the cubical quantity may be divided by a less number; for example, in greenhouses, where the temperature required is 60°, 30 should be the divisor; for 75°, 20 will be sufficient.

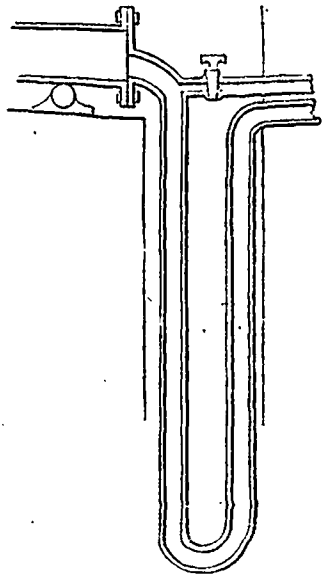


Fig. 1927. PIPES.

In calculating the quantity of pipe due attention must always be paid to the heat lost by ventilation, as well as the power of glass in radiating cold, 1 square foot of which will cool down 1¼ cube feet of air 1° per minute, when the external temperature is 30°; in a greenhouse, therefore, we ought to have sufficient power to warm 1¼ cube feet of air at least for every square foot of glass contained in the building.

Warming by Steam is attended with more expense than by water heated to circulate through the same extent; the boilers made use of are of various shapes, and are generally either of wrought-iron or copper. The tubes are generally of the same material as the boiler, though cast-iron is very much used, and earthen pipes have been tried, but with them there is some difficulty in making a good joint.

A mill at Watford in Hertfordshire, *106 feet in* length, and 33 in width, consisting of 4 stories, and used for the manufacture of silk, was one of the earliest warmed by steam. By this method it was found that all smoke was avoided, as well as the danger of setting fire to the raw material; there was also great economy, and an equable heat at all times maintained. Outside the mill a small furnace was built, where, from the upper part of the boiler, rises a main, from which the steam was conveyed by another pipe, suspended to the ceiling of each floor in its progress towards the top: the upper story, which was 8 feet in height, had a pipe of 3 inches in diameter; the next story downwards, being 8 inches higher, had one of 4 inches; the next, which was 9 feet high, had one of the same diameter, and on the ground floor or lower story the pipe was 5 inches in diameter; at the top of the mill was a cistern of water, which feeds the boiler.

The pipes of each story are furnished with valves, which regulate the supply of steam, and there are others ingeniously introduced to collect and discharge the condensed steam into the boiler below, which is most important: the pipes are all laid with a slight inclination to accommodate this running off of the water immediately it is formed; for if the steam meet with a great surface of cold water, it condenses so rapidly as to endanger the boiler and pipes, should they not be strong enough to resist the external pressure: it has been stated that the quantity of coal necessary per day to warm such a building as the one described is about 1400 pounds.

Warming by Air has been preferred in many instances to either steam or hot water: a stove or furnace is contrived in the basement, and the air from the outside is introduced, passing under the same, and enters a chamber which surrounds the furnace, so that in its passage it becomes heated, when it is afterwards conducted to the several apartments required to be warmed: great attention should be paid to the closing of all external doors and windows when this plan is adopted, and therefore it has been objected to in manufactories, churches, and hospitals, or where any great number of persons are assembled.

At the Reform Club House in Pall Mall the objections are obviated by the introduction of a large fan, which revolves in a cylindrical case, by means of a small steam-engine fixed in the basement, and by which 11,000 cube feet of air are forced every minute into a tunnel, built to receive it, in the lower part of the building; the air then flows through a series of cells formed in steam cases, where it cannot become scorched, but is heated to a temperature of from 75° to 85° Fahrenheit, and from thence it enters a brick chamber, built to contain it, and from which it is let off, in a variety of flues, into the several rooms to be warmed: by the aid of dialled valves and registers, the quantity of air admitted is nearly under control; there are three cast-iron chests, each of which is a cube of 3 feet;

these have seven parallel cast-iron cases, 3 inches in depth; into these cases the steam is conducted by proper pipes, and between them the air to be warmed passes. The steam-engine, of 5-horse power, which is on the expansive principle, serves other purposes than that of turning the ventilator, and consumes about 2 cwt. of fuel in twelve hours.

This principle is the reverse of that already described as adopted at the New Model Prison: here we have genial air thrown in by the fan, and its circulation insured by pressure from below, and not by exhaustion from above; the pure cold air is obtained, and raised to an agreeable state of temperature, after which it is diffused into all the halls, passages, and rooms around them. When air is pumped out, and no abundant supply forced to succeed, what remains in an apartment is likely to be so highly attenuated as to prove injurious to health: when attention is paid to the ventilation and passing off the vitiated air, the pressure system is preferable. Fans of sufficient size may be driven by means of steam power with such velocity as to produce ventilation throughout the most extensive buildings: condensed air has a much more agreeable and healthy effect upon individuals than can be obtained from highly rarefied air: a person breathing condensed air does so with facility; he feels the capacity of his lungs enlarged, and his respirations are less frequent; in rarefied air the breathing is attended with difficulty, and in consequence of this, in some of the deep mines in France, the men work in condensed air pumped down from a chamber above: when those workmen are about to descend they shut the door over their heads, and then turn a cock, which is in connection with the condensed air on the under shaft: an equilibrium is established in an ante-room, by the entry of the dense air from below, and then the man-hole can be opened for the men to descend: here they work in air maintained at a pressure of three atmospheres by the action of pumps driven by an engine; in such an atmosphere the miners gain additional strength, and work without fatigue. The fanner or blower is made in various forms; the most common is that with four arms or blades, working in a box; the air entering in the centre is discharged at the circumference; in some of the most powerful, the air is made to enter at the sides of the blades throughout their whole extent, and to discharge it at its circumference; by unscrewing one side of the cylindrical box, in which a fan works, it will be readily seen which way the air proceeds, if a rapid motion be given to it; the external casing is generally made air-tight, and the air is conducted by a pipe to the fanners, at the opposite side to which it is desired it should be discharged.

The larger the fanner, the greater is the economy with which its supply of air can be had, and they are less subject to noise; those making 2000 revolutions in a minute are exceedingly disagreeable throughout the whole neighbourhood where they are used; quantity of air, and not velocity, is the object to be attained, and for this purpose fanners of from 10 to 20 feet diameter, moving slowly, are to be preferred: powerful blasts of air are not required for ventilation, and therefore rapid movement to the fanner can be dispensed with.

Ventilation probably was first attended to in the mining districts, but nothing on this subject could be effected upon a proper basis until Priestley defined the composition of the atmosphere; no definite meaning could be given to the word ventilation until the nature of the air itself was known; to him, Scheele, Dalton, and Cavendish, are we indebted for our knowledge upon these subjects.

Before the employment of many persons in a small space, particularly in mines, the necessity for ventilation was not rendered so apparent: and the practice first adopted there, to throw in a succession of currents of wholesome air, has been latterly introduced to disturb the vitiated atmosphere of our crowded halls and ordinary dwelling-houses. The architect and civil engineer have been roused to contrive and invent means by which life may not only be supported but endured, when confined in rooms robbed of their fair proportion of oxygen by the modern luxuries of warming and lighting by gas. A man making twenty respirations in a minute is said to inhale at each 16 cubic inches of air, or 320 cubic inches in a minute: of this quantity 32 cubic inches of oxygen are consumed, and 25 inches of carbonic acid gas are discharged; so that, if his life endured for 50 years, it has been estimated he would inspire 166 tons of air, consume 18¼ tons of oxygen, and discharge nearly 20 tons of carbonic acid from his lungs, or, in other words, nearly 5½ tons of carbon: allowing 10 cubic feet of air per minute to each individual, the consumption for 1000 persons assembled in a theatre or church may in some degree be estimated: as may the necessary quantity for any given number of persons in rooms of different dimensions.

Of the atmosphere 78 per cent. is nitrogen and 22 per cent. oxygen, and the quantity of carbon and moisture evolved by a single individual in a minute is stated to be 3·27 grains of carbon, and 3·2 of water: so that 1000 persons would evolve in an hour 28 pounds of carbon, and nearly as much water.

It is not so easy to determine the quantity of air required for ventilation, as this is so much affected by temperature: Dr. Arnott informs us that air expelled from the lungs vitiates twelve times its bulk of pure air, so that a man vitiates every minute nearly 4 cube feet, and agrees that 10 cubic feet of fresh air per minute is the smallest allowance that should be made for each individual. To produce motion in the air, or, as it is termed, ventilation,

heat properly applied has been found most efficient. Air at an ordinary temperature expands $\frac{1}{356}$ part for the rise of every degree of the thermometer: thus it becomes, as it advances in temperature, specifically lighter, and consequently has an inclination given to it to mount higher, and give place to the colder air, which sinks on account of its greater density: this takes place in the common chimney, the draught of which depends on the difference of temperature at the top and at the bottom; the air at the lower end, by being heated, rises and passes off at the upper, its place being supplied by the pressure of the surrounding air to fill up the vacuum. Supposing v to denote the velocity in feet per second, g the accelerating force of gravity, ($=32{\cdot}2$ feet per second,) a the rate of expansion for 1° of the increased temperature, t' the temperature of the heated air as it enters the chimney, and t, that of the external air, we shall have this formula,

$$v = \sqrt{[2ghg(t'-t)]},$$

the velocity of the draught being as the square root of the height of the chimney, and the square root of the excess of temperature of the lower opening: and as the same quantity of air passes through every section of the chimney in the same time, the velocity must be inversely as the density, and therefore decrease from the bottom to the top.

Air forced into a chamber by mechanical means is often used for the purposes of ventilation: at the Bank is a square box, furnished with a pump with a loose piston, which has large-valved openings, and by it 11,000 cubic feet of air per minute are driven through the various offices; at the Houses of Parliament a large shaft, with a fire made in it near its summit, exhausts the air from the several apartments, in the same manner as in coal mines, and other deep workings.

The practice adopted in deep mines to obtain ventilation seems to have given rise to all the modes now made use of in our buildings for the same purpose: suppose there are two shafts, which descend to the bottom of the mine, one is called the downcast, the other the upcast shaft; by the first the air descends, and by the other the vitiated air mounts and is dispersed. This movement is effected by constantly keeping up a large fire at a little distance from the bottom of the upcast shaft, and making use of it as a chimney: by this simple contrivance, the descending air may be made to pass through and along every working of the mine; in some instances, it travels at the rate of 30 miles per hour, driving all the lighter gases before it; numerous doors are introduced to shut off the course as well as to direct it; should any of these be left open, the whole system of ventilation will be destroyed.

Theatres are frequently ventilated by means of a funnel placed in the ceiling of the pit, and having its exit through the roof, upon the top of which is a movable cowl: by placing the large chandelier, or a multitude of gas-lights, immediately below the opening in the ceiling, the air about it becomes so rarefied, that it rapidly mounts the funnel, and passes out at the mouth: generally this part of the operation, viz. the exhausting or pumping out, is tolerably well effected, but not so the admission of a warm and pure air to supply the wants of the spectators, each of whom requires air for 20 respirations per minute.

Lighthouses may be classed among the works of the greatest public utility and importance to a maritime nation: we have already described many erected after the Eddystone; the form at present usually adopted, when on land, is that of Ramsgate Harbour, which is circular on the plan throughout, the rooms for the attendants being on the ground floor, and a winding staircase conducting to the lantern.

A Select Committee appointed by the House of Commons made a report in 1834 upon the state and management of lighthouses, floating lights, buoys, and beacons, from which we gather the most valuable information that could be afforded: to Joseph Hume, Esq., the chairman of the committee, the com-

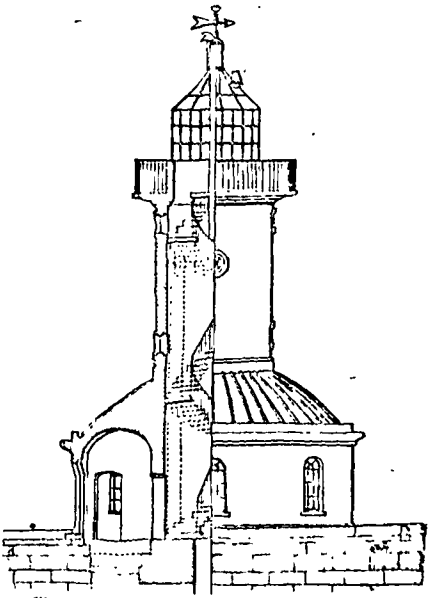


Fig. 1928. RAMSGATE LIGHTHOUSE.

mercial world is infinitely indebted for the mass of evidence there brought forward on this highly important subject, as the means of preventing many of those fatal accidents to which our shipping is so constantly exposed.

Till the date of the report, the lighthouses which surrounded our coast were managed by a variety of systems, and, instead of being under the superintendence of the Government, were, many of them, in the hands of private individuals: the whole appear to have been built at various times, by slow degrees, and as the naval and commercial interests required them.

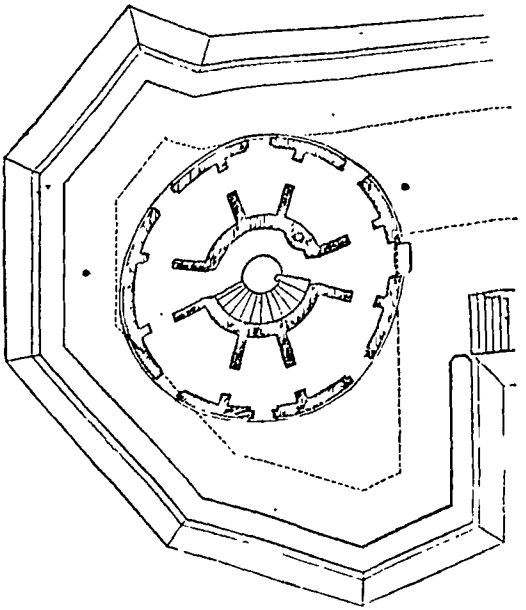


Fig. 1929. PLAN OF RAMSGATE LIGHTHOUSE.

There were belonging to, and under the management of, the Trinity House of Deptford Strond in the year 1834, 108 lighthouses and 18 floating lights, and throughout the United Kingdom 198 lighthouses and 21 floating lights. This fraternity, or college of seamen, seems to have existed prior to Henry VIII., but in the sixth year of that monarch's reign they were incorporated by charter, as the Master, Wardens, and Assistants of the Guild Fraternity of the Most Glorious and Undivided Trinity, and of St. Clement's, in the Parish of Deptford Strond, in the County of Kent. Queen Elizabeth afterwards gave them fresh powers, to erect and preserve beacons and signs for the sea, but it does not appear that this fraternity erected any lighthouses till the year 1676.

The public lights of Scotland were under the Commissioners for Northern Lighthouses, incorporated by the 38 George 3. chap. 58.; there were 25 lighthouses under their management: those of Ireland were under the superintendence of the Ballast Board, a corporation consisting of the mayor and sheriffs of Dublin, three aldermen, and 17 other individuals, who had the control and management of 35 lights; there were several other lighthouses held under lease from the Crown.

Lighting. — The first method employed for lighting these buildings was undoubtedly coal fires, unaided by reflectors or any mechanical or optical arrangements: to this succeeded the use of candles, and till a late period we find them generally adopted: the next improvement was the Argand burner, introduced on the focus of a parabolic reflector: this instrument is made of silver, strengthened with copper; it is about 3 or 4 inches in focal length, and 21 inches in diameter; the number and arrangement of reflectors in each house depend on the light being fixed or revolving, as well as upon the situation and importance of the lighthouse: one of the methods much used in France is to place a large Argand lamp, with four concentric wicks, giving a very powerful light, in the centre of the lantern, surrounding it with a series of glass lenses, of a peculiar construction, and using a refracting, instead of a reflecting instrument to collect the light, and only one lamp instead of a number. The lens is a very beautiful instrument, about 30 inches square, plano-convex, and formed of separate rings or zones, whose common surfaces preserve nearly the same curvature as if they constituted portions of one complete lens, the interior and useless part of the glass being removed. To form a lens out of one piece of glass of such a magnitude would be scarcely practicable, and if it were, the thickness of the glass would materially obstruct the light: a lens so constructed gave as much light as nine of the ordinary reflectors in common use, and the consumption of oil in the burner was as great as in seventeen of the Argand lamps.

Lieutenant Thomas Drummond, who was employed on the Trigonometrical Survey of England, had his attention directed to the subject of signal lights, in consequence of the great difficulty he experienced in observing distant stations, particularly when it was required to see Leith Hill, in Surrey, from Berkhampstead Tower, in Hertfordshire; and it

appeared very desirable to procure a brilliant light, capable of penetrating the almost constant haze which impeded his observations. He began his inquiries by repeating some of Berzelius's experiments on the distinctive qualities of the different earths before the blow-pipe; that assigned to lime was the property of emitting, when so heated, a peculiar bright light, and which he found produced one so distinct that every particle of lime could be seen with the naked eye. After this experiment, the idea presented itself, that if an apparatus could be made, containing a ball sufficiently large, and kept in a state of intense ignition, its effect, when placed in the focus of a reflector, would exceed that of any light hitherto used.

After many experiments, the extraordinary intensity, as well as useful application of this light was detailed in two papers published in the Philosophical Transactions for 1826 and 1831: it was afterwards fitted and adapted to the purposes of a lighthouse; the apparatus consisting of a lamp, (fig. 1933.), which admitted at the same time through the apertures *o* and *h* the two gases, hydrogen and oxygen: they came from separate gasometers, and were not suffered to mix until they arrived at the small chamber c, of which fig. 1931. is a section; into this chamber the oxygen gas from the inner tube is projected horizontally, through a series of very small apertures, and the hydrogen gas rises vertically through similar apertures at *d*. The united gases then pass through two or three pieces of wire gauze, placed at *e*, and being thus thoroughly mixed issue through the two jets against the ball, *b*, fig. 1933. To prevent the wasting of the ball opposite the two jets, and at the same time to diffuse the heat more equally, it is made to revolve once in a minute, by means of a movement placed underneath the plate *m*, and with that the wire *f*, carrying the ball and passing through the stem, is connected: notwithstanding this arrangement, the effect of the heat is such as gradually to cut a deep groove in the ball, so that at the end of about 45 minutes it becomes necessary to change it; to effect this a wire, *ab*, (fig. 1930.) passes through the focus of the reflector, and upon it are placed a number of balls, at A, required for any given time; these, by means of the shears, *s*, are admitted between the plates, *p*, *p*, and hence are permitted to fall, in succession, to the focus. *f* represents the focal ball, about two minutes before the change; the ball at *g* falls into the position *i*, where it becomes gradually heated; at the end of that time the curved support, *t*, moving on a pivot, is thrown into the position represented by the dotted line, by the momentary descent of the ring *r*, which receiving an impulse from the weight W acts upon the extremity *u* of the support; *f* falls, but it is prevented from descending more than its own

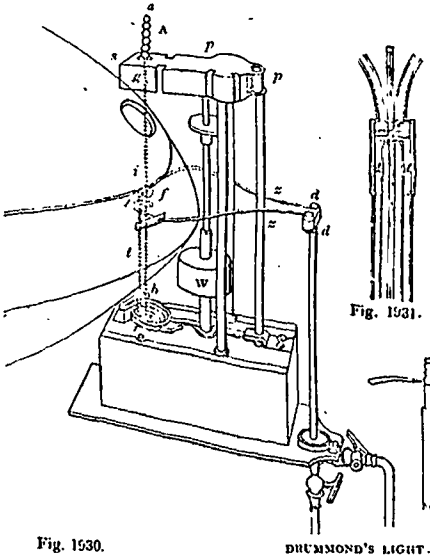


Fig. 1930.

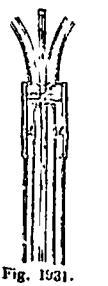


Fig. 1931.

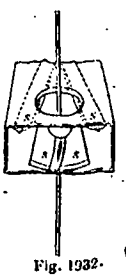


Fig. 1932.

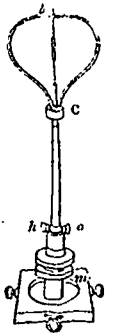


Fig 1933.

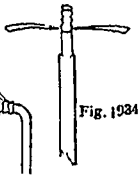


Fig. 1934

DRUMMOND'S LIGHT.

diameter by the loop *l*, and *i*, following it, occupies the focus; the support *t* being immediately released, returns by the action of a spring to its former position, retains *i*, and suffers *f* to escape through the loop into the cistern. The wire *ab*, and the support *t*, revolve together, and carry round the focal ball, which is ignited, as in fig. 1930. by the two jets, *z*, *z*. These jets, which are movable round the joints *d*, *d*, enter through small apertures cut in the sides of the reflector, and are easily adjusted to the proper distance from the

ball: should it be required to diffuse the light equally, the renewal of the lime may be effected by using a cylinder instead of a ball, which, being gradually raised while revolving, brings fresh portions in succession opposite the jets.

In a reflector, a cylinder occasions partial shadows at the top and bottom, but the simplicity and certainty by which it may be renewed entitle it to be preferred: the apparatus to supply the gas consists of two strong cylinders, 3 feet high, one to contain the oxygen, the other the hydrogen; these gases are compressed, two or three times, the latter by being generated under pressure, the former by being pumped in. To each of these gas-holders is attached a governor, so that whatever be the variation of pressure in the gas-holder, provided it exceed that of the governor, the gas issues with a uniform and constant stream, in the present instance under a pressure of 30 inches of water: all attempts made to apply the Drummond light and voltaic light have hitherto failed, in consequence of the many great and practical difficulties with which these modes of lighting are accompanied, and the usual methods adopted are those of the lighthouse of Corduan, and others on the French coast.

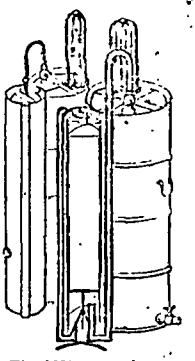


Fig. 1935. DRUMMOND LIGHT, GAS CYLINDERS.

Mr. R. Stevenson, however, in his report upon the Drummond light, observed that on several occasions during a dense haze it had been seen, though not with brilliancy, while the reflected and lens lights were totally eclipsed: this light was so intensely brilliant, that the observers on the Leith road, in a favourable state of the atmosphere, saw their shadows strongly marked at full length across the road, at a distance of 13 miles from Gullan hill, where the experiments were made. With regard to its application to lighthouses, Mr. Stevenson was of opinion that with the then state of the apparatus, it was not possible to maintain a steady light; the heat of the united flames of these gases was so intense that it destroyed platina, and all the substances applied to it; independently of this, the very explosive nature of the oxy-hydrogen gas was an objection, and great attention was necessary to keep up a constant flame.

Gas Lighting.—For gas manufactories it is necessary to have premises of sufficient extent to contain buildings for the retorts, as well as ample space for the gasometers, purifying apparatus, and stores of coal, pipes, &c. employed in manufacturing, or in conveying the gas to the places required: the situation usually chosen for these works is the lowest that can be obtained; coal gas being lighter than air is sure to rise, and can only be made to descend by the application of pressure. The plan given is that of some gas-works constructed by the writer for a town in Kent, of 6000 inhabitants, about 30 years ago.

Retort-house is generally of brick, and sufficiently large to contain the requisite number of retorts, which are of a cylindrical or elliptical form, of cast-iron; they are placed in rows

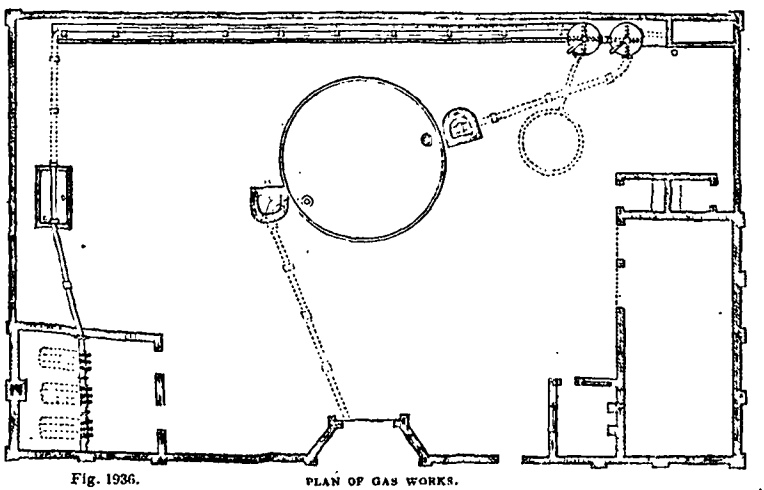


Fig. 1936. PLAN OF GAS WORKS.

within a brick oven, where they are so surrounded with flues that the heat is distributed equally.

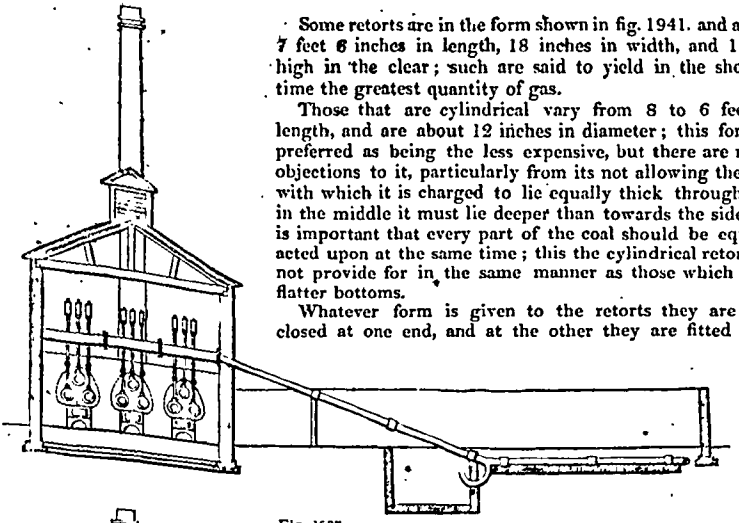


Fig. 1937. SECTION OF RETORT-HOUSE.

Some retorts are in the form shown in fig. 1941. and about 7 feet 6 inches in length, 18 inches in width, and 1 foot high in the clear; such are said to yield in the shortest time the greatest quantity of gas.

Those that are cylindrical vary from 8 to 6 feet in length, and are about 12 inches in diameter; this form is preferred as being the less expensive, but there are many objections to it, particularly from its not allowing the coal with which it is charged to lie equally thick throughout: in the middle it must lie deeper than towards the sides; it is important that every part of the coal should be equally acted upon at the same time; this the cylindrical retorts do not provide for in the same manner as those which have flatter bottoms.

Whatever form is given to the retorts they are cast closed at one end, and at the other they are fitted with mouth-pieces, also made of iron, into which is fixed the conducting pipe, which carries away the gas as it rises from the coal.

The cover or lid requires to be well closed: this is accomplished by an iron frame, through which a long screw passes to the centre of the cover, where it enters; by this means the retorts can be closed immediately they are charged with coal: the joints round the cover are closed more perfectly by the application of a lime-lute, which prevents the gas as it is generated from making any escape.

These retorts are liable to accidents: they seldom last more than six months, and often not so long; for they indicate decay both on the out and inside, the former caused by the heat, and the other by the action of the coal itself.

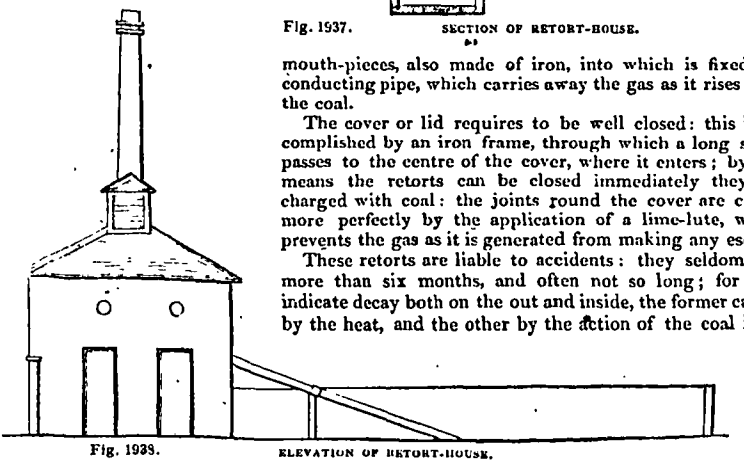


Fig. 1938. ELEVATION OF RETORT-HOUSE.

The iron appears to increase in bulk, and in time becomes soft, resembling finely laminated black chalk. Particular attention is required for their setting in large establishments: several are set in one frame or oven, with the fireplaces beneath them; the flues are so contrived that there is not only an equal distribution of heat, but it is sufficient to decompose all the coal put into them, which if not properly done, all the volatile substances will not be liberated, and a loss will be proportionately sustained: each retort is usually charged, after being properly heated, with a bushel of coal, thrown into it by a long semicircular iron shovel, or scoop, which spreads it throughout into a thin layer; this remains subjected to the action of the heat of the

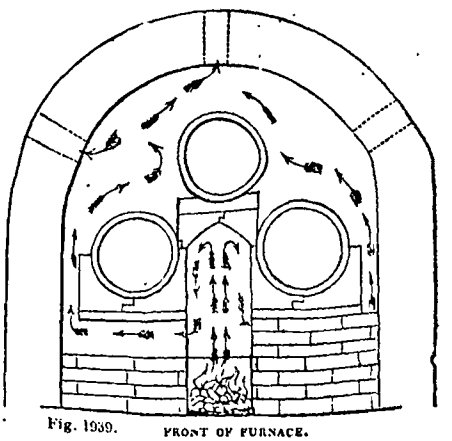


Fig. 1939. FRONT OF FURNACE.

oven for 6 or 8 hours, when the plate which closes the mouth of the retort is withdrawn, and a volume of flame pours out; after this the residue, which is coke, is drawn out by

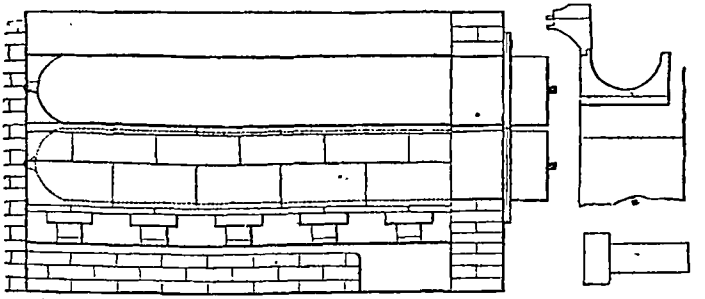


Fig. 1940. SECTION OF FURNACE AND RETORTS.

means of iron bars with crooked ends, and water thrown upon it, or it is allowed to descend into a place prepared to receive it.

The quantity of coke obtained after distillation varies, as coal loses from 20 to 35 per cent.: it is usually, however, about half as much more than the bulk of coal thrown into the retorts, a bushel yielding 1½ bushels of coke. The quantity of coal required to heat a retort is about a fifth of the quantity with which they are charged, and 1 cwt. yields from 300 to 500 feet of gas.

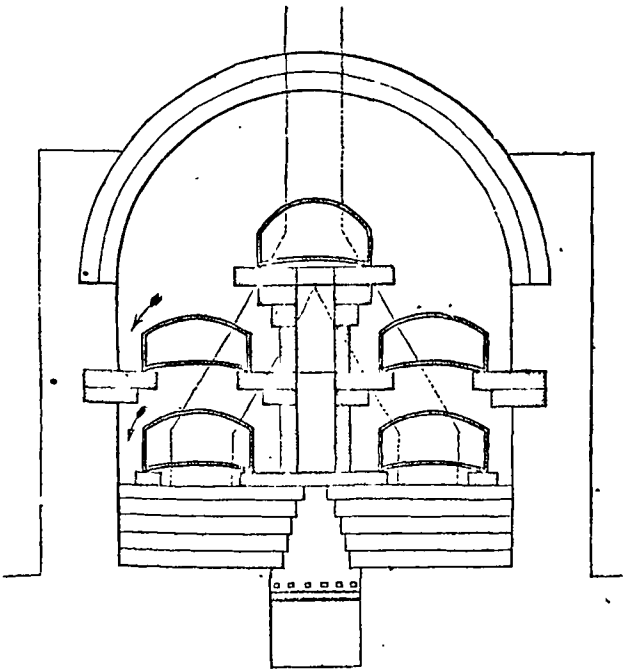


Fig. 1941. TRANSVERSE SECTION OF RETORTS.

Great attention is required in so carbonising or distilling pit coal, that the carburetted hydrogen may be produced in the largest quantity; and upon the economy and care carried into this operation depend the successful results of any establishment undertaking to light a city. As soon as the retort into which the coals are put to undergo decomposition becomes red-hot, atmospheric air and steam are given off, and the tar is distilled from it, together with hydrogen and ammonia, in the state of gases, which continue to be evolved as long as the retort is kept up to this heat; when this is increased, the pyrites of the coal yields sulphurous acid, which is found united with ammonia; the residuum after distillation is carbonised coal or coke.

The first gas that comes off gives a very feeble light; that produced at a vivid red heat consists of bicarburetted hydrogen or olefiant gas of the best quality, and affords the brightest light: in every 100 measures obtained from good coal, the products at the first giving out are: —

Bicarburetted hydrogen	82·5
Olefiant gas	13·
Carbonic acid	3·2
Azote	1·2

The whole combined having a specific gravity of ·650: when the retort has been heated 5 hours, it may be thus stated: —

Bicarburetted hydrogen	56·
Olefiant gas	7·
Carbonic oxide	11·
Hydrogen	21·3
Azote	4·7

The specific gravity of the compound being ·5.

At the end of 10 hours it contains 20 of carburetted hydrogen, 10 of carbonic oxide, 60 of hydrogen, 10 of azote, and the specific gravity is only 0·345.

In the first hour of distillation one-fifth of the whole quantity is given out, and the remainder in tolerably equal quantities for each successive hour, until the whole, which amounts to about fifty-four parts out of the hundred, is obtained: it is consequently advisable to commence the operation by making the retort cherry-red; the best gas being then produced, when a portion of the tar is converted, instead of being distilled over. At the commencement of gas-lighting it required half as much coal to heat a retort as it was charged with; now five retorts are heated in one oven by a single furnace, and one-third the contents of the retorts is sufficient for the purpose: 65 per cent. of coke remains in the retort after distillation, and its volume is increased in the proportion of 4 to 3: it is now preferred for heating the retorts, and its power may be estimated at 65 per cent. of the coals consumed. When the retorts have been some time in use, it is found that their external capacity is diminished, in consequence of an incrustation of carbonaceous matter within them: this has sometimes been removed by throwing in jets of heated atmospheric air with considerable force, when the retort is heated to redness; it has been suggested that this might be effected by common air, if applied in sufficient quantities, which would burn away the extraneous matter.

The Hydraulic Main is a strong cast-iron pipe, usually about 12 inches in diameter, of a sufficient length to receive all the perpendicular pipes that convey the gas generated in the several retorts: this main is made perfectly horizontal, and supported on the brickwork which covers the ovens. The gas leaves the retort by means of an upright conducting iron pipe, about 3 inches in diameter, and 4 or 5 feet in length, fixed at one end into the mouth-piece and mounting perpendicularly, curving at the top, before it is allowed to descend and join the hydraulic main; through this pipe the impure gas passes.

The hydraulic main contains a certain quantity of cold water, for the purpose of condensing the several substances which constitute the first-formed gas; one end of the main is firmly closed by means of a flange; the other has a similar contrivance, and a little above its diameter is attached the pipe through which the gas passes: at the end is a semicircular piece of iron, which maintains the water at a uniform height.

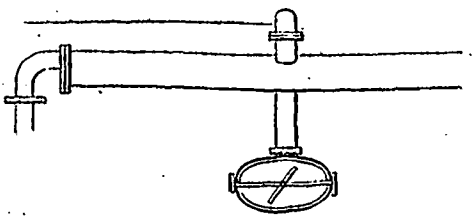


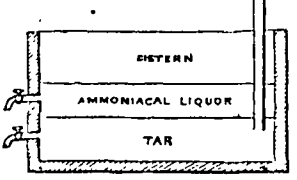
Fig 1942. HYDRAULIC MAIN.

The upright pipes, which are bent at the top, and convey the gas into the hydraulic main, dip 2 inches or more into the water, obliging the gas to flow through a portion of it before it rises into the upper half of the main and passes off. The tar deposited in the water from this process is drawn off by means of pipes, whilst the greater portion of the ammonia, from its strong affinity for water, combines with it.

The Condenser, which receives the gas from the hydraulic main for the purpose of cooling it, is a large cistern or tank constantly immersed in cold water; its form may be either square or circular; but it must be so arranged, that when the gas has once entered it may be obliged to pass over a considerable cold surface before it can escape: it is usually covered with wrought-iron plates pierced with holes, into which are inserted a number of tubes; these are 4 inches in diameter, and attached by flanges and screws, connected in pairs at top, by means of curved or saddle tubes. The chest or vessel which is so covered is divided by vertical iron partitions, as many in number as there are pairs of tubes; and as these vertical plates do not touch the bottom of the chest, the gas is obliged, or rather made, to pass up and down this series of partitions and pipes, or from one

compartment to another. In the passage of the gas it is at last cooled down to the temperature of the air, and made to deposit the whole of its tar and ammoniacal liquor, which pass off into the tar cistern beneath, where the ammoniacal liquor floats at the top, and is drawn off by means of pipes placed there for the purpose; or there are two pumps, one which passes to the bottom, to lift up the tar, and the other enters only the part containing the ammonia, where it can be pumped out, without bringing up the tar. A chaldron of coals yields 1½ cwt. of tar, and produces from 15 to 18 gallons of ammoniacal liquor.

Other condensers have been introduced, which consist of a series of ascending and descending bends of pipes, where the tar, of two or three qualities, may be drawn off, and the ammoniacal liquor easily discharged: it has been estimated that about 10 square feet of condenser is required to cool 1 cube foot of gas per minute; and that when 10 cubic feet of gas are produced per minute, a cooling surface is required, equal to 100 square feet; or in establishments where 100,000 cubic feet of gas are produced every 24 hours the condensing surface must be from 800 to 900 square feet.



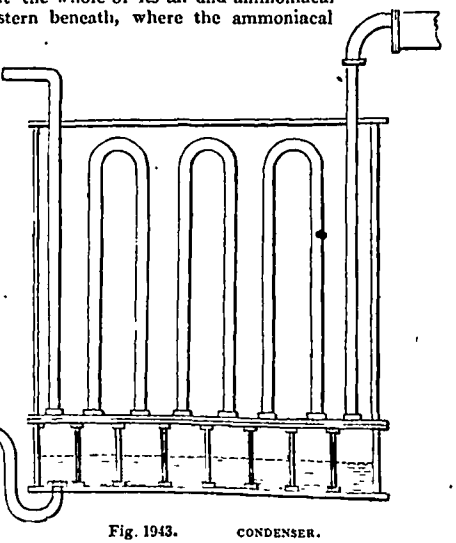


Fig. 1943. CONDENSER.

The Purifier. — As it is necessary to separate the sulphuretted hydrogen and carbonic acid gases, which is not possible by mere cooling, and to clear the coal gas from other impurities injurious to health, which also corrode the pipes, as it passes through them to the burners, and injures the colour of the flame, it is subjected to a chemical action, by passing through lime and water, mixed together to the consistence of thick cream; hence called cream of lime. The sulphuretted hydrogen and carbonic acid are taken up by the lime, and the water absorbs any ammonia that may remain.

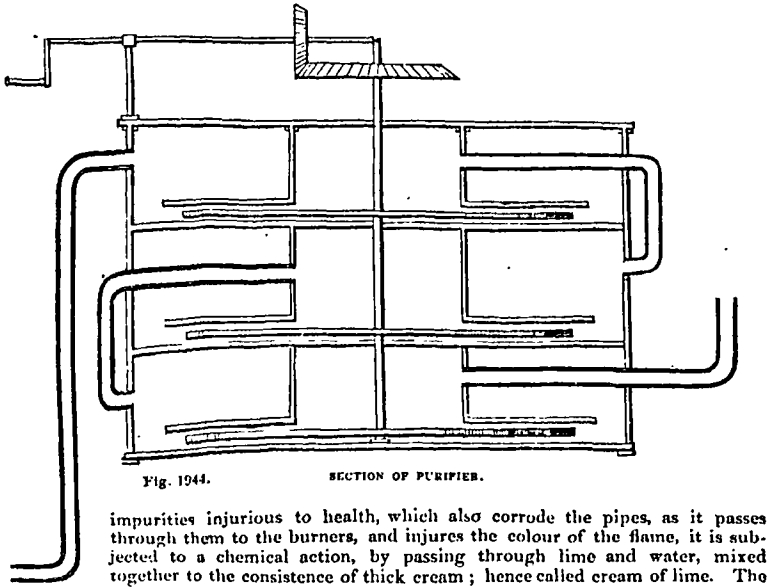


Fig. 1944. SECTION OF PURIFIER.

When coal gas contains 5 per cent. of these gases, every 100 cube feet will require 1¼ pound of lime, or about $\frac{1}{8}$ in weight of the coal subjected to decomposition, with which as much water must be mixed as will make it into 1 cubic foot of the cream. The purifier should have a capacity sufficient to hold ¾ of a cubic foot for every 100 feet of gas that passes through it in one operation, and the contents should be changed every 6 hours: 20,000 cubic feet would require 114 feet cube of cream of lime; so that a cylindrical vessel in which it could stand to the height of 8 feet must be 7 feet in diameter.

The purifier is generally formed of three vessels within each other, air-tight, and of a cylindrical form, with an upright shaft in the axis, to which is attached a number of arms or paddles for the purpose of stirring up and agitating the mixture, and preventing the lime from settling at the bottom: as the gas enters at the lower part of the vessel, it passes in air-bubbles through a succession of plates around the edges, where a space is left for the purpose, and in its passage becomes exposed to the action of the cream of lime: in this process all the sulphuretted hydrogen is taken up; this is tested by allowing a portion to escape through a cock, and pass over a piece of paper previously dipped in a solution of sugar of lead, which will become brown if any sulphuretted hydrogen remain: when this is the case, it must be again submitted to the cream of lime.

At large gasworks it has been found necessary to have three purifiers, so connected together that the second is placed rather higher than the first, and the other a little above it, so that the discharge-tube of the highest vessel, which is a little below the top, enters into the upper portion of that which stands lower; by this means the milk of lime in the uppermost vessel is made to rise above its ordinary level, flow over into the second, and then into the third, from whence it is drawn off by the eduction-pipe; the gas is introduced into the first vessel, and passed successively through the others into the gasometer: when the milk of lime is in sufficient quantity to allow the gas in its progression to pass over an entire new surface, it becomes thoroughly purified: its purity may be tested, after it has passed through the vessel containing the lime, by means of a siphon-tube with a stopcock; this, inserted in the cover of the purifier, may have one end in contact with a solution of acetate of lead, which will become turbid, when it is necessary to renew lime in the machine. It is very desirable that gas should be rendered perfectly pure, and that no sulphuretted hydrogen should remain; it has been recommended to make use of pyrolignite of lead for the purpose; the only objection is its cost: coal-gas contains also sulphuret of carbon, which gives out sulphurous acid when consumed, and which it is exceedingly difficult to prevent.

Various other methods have been tried to render gas pure: one was putting a small quantity of water to the lime, and mixing it to such a consistence that it could be spread into cakes over perforated iron plates, through which it was allowed to pass; another was to pass it through red-hot pipes, in which was previously placed black oxide of iron, iron filings, &c., or other matter capable of oxidation, which separated the sulphuretted hydrogen and carbonic acid from the carburetted hydrogen. By the former plan the necessity of evaporating the waste liquor is avoided, and the product presumed to be better, retaining the whole of its olefiant gas, from which the whiteness of the flame is said to arise, whereas this latter, being slightly soluble in water, loses some of this quality in its passage through the milk of lime: it is beneficial to submit the gas in the purifier to the pressure of a column of water about 2 feet in height, and an Archimedean screw has in some cases been used for the purpose.

Gasometers are now made of a cylindrical form, as this figure is the most capacious for the quantity of metal used; its height ought to be equal to its radius, to comply with this condition: sheet-iron is usually employed for its construction, and the cylindrical form is strengthened by the introduction on the inside of cross iron rods, both at its top and bottom; the top is like a very flat cone, the rods radiating from the centre to the outer rim. The bottom rim is cast-iron, held to the upper by perpendicular rods bolted through them; oblique and other rods are introduced in large gasometers, when additional strength is required. The gas-holder has on the upper rim several rings, placed at the ends of the perpendicular rods, to which rings the chains are fixed, which pass over the pulleys, to balance it in its rise; this is aided and performed most effectually by attaching to the other end of the chain a weight acting as a counterpoise.

Around the gasometer are three perpendicular iron columns, placed triangularly, over which the chains pass, to mark the rising or falling of the gas-holder; a greater number of columns are necessary when the diameter is considerable, to keep it steady. The gas-holder is made to descend into a cistern of water, constructed either of brick or cast-iron: as the gas-holder sinks, it of course loses a proportion of its weight equal to the quantity of water it displaces; so that when entirely immersed, as it is when nearly empty, it exercises little or no pressure, but when entirely out of the tank or water cistern its pressure is considerable; to render the escape of the gas equal, which is important, it is necessary so to adjust the balance chain, that throughout its motion it shall be equal to half the weight which the gas-holder loses by immersion.

The size of the gasometer depends upon the quantity it is required to contain: one 42 feet in diameter and 23 feet in height will contain 30,000 cubic feet, and the lower

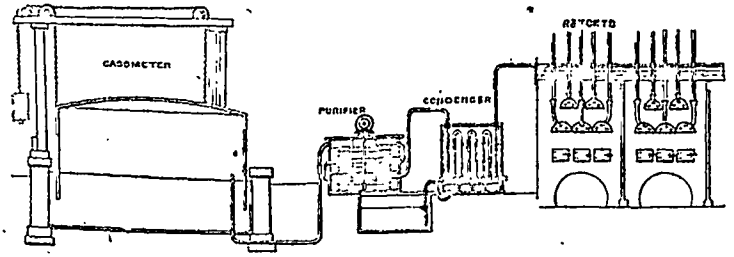


Fig. 1945. APPARATUS TO GAS MANUFACTORY.

vessel or cistern into which it plunges is made somewhat larger, as there is usually a pressure allowed, which makes the water stand on the outside one or two inches higher than within, which is necessary.

Before the gas is introduced into the gasometer, it is usual, after it has left the purifier, to pass it through a large revolving meter, where its quantity and temperature are exactly measured: some of these machines, in large works, are capable of measuring 30,000 or 40,000 cubic feet per hour, and by means of contrivances attached to them, register the quantity as it is made, both by night and by day. Such is the gas-meter, now in general use, and the section perpendicular to its axis shows its arrangement. The interior consists of a hollow wheel or drum, divided into four compartments by as many thin plates; this is made to revolve freely on its axis within an air-tight case, which as well as the lower compartments of the wheel is filled with water to a level a little above the axis on which it moves: each compartment has two apertures, one for admitting, the other for discharging the gas; and these openings are so placed, that when it enters one compartment, its escape must be beneath the surface of the water. The gas is admitted by the pipe, which is bent upwards, so that its mouth internally is raised a trifle above the water; it then flows through into that

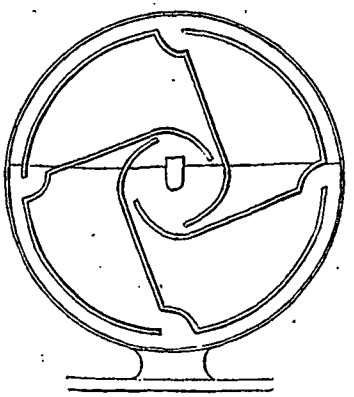


Fig. 1946. GAS METER.

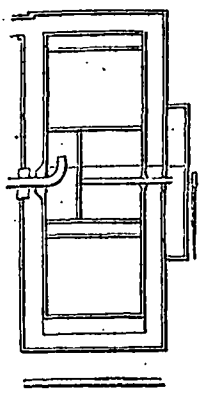


Fig. 1947. SECTION.

compartment which is under water, its pressure on the surface of which causes this division to rise, and the cylinder to revolve on its axis; another aperture then dips into the water, and the gas is driven out as it enters, and so on in succession: the inner cylinder with its cog-wheel attached continues to turn round, and the gas passes off: it is easy to fix upon the machine a dial-plate, which indicates the quantity passed through it by one revolution or move.

The inner cylinder is made to turn freely on the axis, passing partly through it; this axis is fixed at one end to the revolving cylinder, and kept steady in its motion by the cross bars; one end of the pivot is made to work in a hole drilled at the side of the pipe, by which the gas is introduced; the other end projects beyond the inner cylinder, and reaches through the hole in the outer cylinder to a cup placed over it, which contains a hole, in which it turns; within this cup is a cog-wheel, which works by means of others the hands of the dial-plate, in the same manner as a clock movement. To use this machine water is poured into it by means of a pipe attached to the small outer cup, which regulates its height within.

The Gas Governor, which modifies the pressure of the gas-holders, consists of a small gasometer, the interior of which is in direct communication with the pipe through which

the gas enters: from the gasometer it is distributed into the mains, by means of the pressure exerted upon it, and by the proper regulation of the valves, which command the apertures connected with them. The pressure by which motion is given to the gas in the mains is measured by the outside height of water in the cistern, into which the gas-holder is plunged; its velocity in its passage through a main increases in the ratio of the square root of the pressing column of water upon the gasometer; so that by adding to this it may be made to pass either more rapidly or to a greater distance. In laying down the mains, that they may distribute it as equally as possible, it is necessary to take into consideration the velocity of discharge at the several distances.

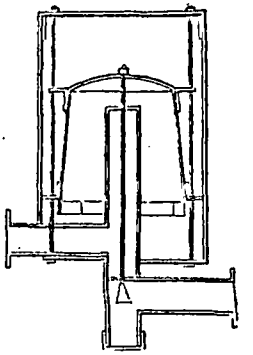


Fig. 1948. GAS GOVERNOR.

Laying down the Mains. — All the pipes employed whose diameter exceeds 1¼ inch in the interior, are made of cast-iron, in lengths of from 6 to 8 feet; their ends fit into a wide socket joint, the end of one pipe being cast with a nozzle, inserted into a socket at the other: after these are inserted, hemp soaked in tar is driven into the joint around the nozzle, and over this is put a luting of clay, within which is poured hot lead, which forms a ring in the socket; this is tightly driven with a blunt chisel, and trimmed carefully. The pipes or tubes, for the distribution of the gas to the several houses or manufactories, are of smaller diameter, though never less than ¼ inch, and made either of tin, iron, copper, lead, pewter, or other compounds; they should, however, all be subjected to proof before they are employed by means of a force-pump.

A pipe 1 inch in diameter and 250 feet in length is sufficient under ordinary circumstances to transmit 200 cubic feet of gas in an hour; and as the volume discharged at the end of a pipe is directly proportionate to the square of its diameter, and inversely as the square root of its length, other calculations may be founded upon it: it is highly necessary that the engineer should, previously to his laying down the mains in a town or city, correctly ascertain the difference of level of every part to be lighted, as well as the quantity of gas to be distributed in the different quarters; whenever streets are wide, it is preferable to lay down a main on each side, as it is far more convenient to attach the service pipes as well as for their repair. The pipes should all be laid, if possible, in a straight line, and with a gradual slope of about 1 inch to every 30 or 40 feet; this slope, after it has continued for about 300 feet, may then, if it be on the ascent, descend the same distance, so that the pipes alternately rise and fall, and are not laid level; otherwise they will not drain off the water that may be condensed within them.

Where the mains are required to be laid at right angles, curved pipes cast for the purpose are used for rounding the corners of the streets, as it is desirable to avoid any line or form that may obstruct the free passage of the gas through them, which is so very subtile that it is necessary to have the pipes cast internally as clean as possible, to prevent friction. At the end of every fall of main, or where two descending lines meet, a reservoir should be formed, to receive all that drains off by them; this reservoir, or siphon, as it is usually denominated, must be proportionate to the duty it has to perform; it is made of cast-iron, of a cylindrical form, its diameter being equal to double that of the mains which fall into it, and the depth is made twice or more that of the diameter; the top is provided with a cast-iron cover, into which is fixed a wrought-iron pipe that descends nearly to the bottom; on the top of this pipe, which rises above the cover some inches, is a screw for the purpose of attaching a small pump, that is applied whenever the condensed water has accumulated, and requires to be drawn out.

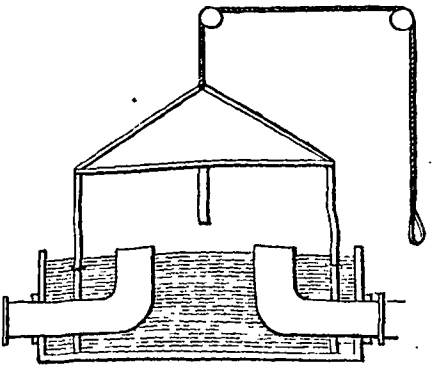


Fig. 1949. SLIDING OR HYDRAULIC VALVE.

Sliding or Hydraulic Valves for passing off the gas into the mains: this operation is sometimes ingeniously performed by means of a small gasometer or cast-iron vessel, which has on one side a pipe communicating with the main, and on the other a com-

munication with the gasometer with a similar pipe. The top cover, which is suspended over pulleys by a balance weight, when raised, allows the gas freely to pass, but when let down, the partition plate, sinking in the water which surrounds the ends of the two pipes, at once prevents any gas from passing from one to the other: the water is maintained at a uniform height by means of a small reservoir attached to the side, which is regularly supplied by a ball-cock.

Pressure Indicator, which measures the pressure in the main and service pipes, is used at most of the large establishments, and is a beautiful contrivance; by it is ascertained the excess or deficiency of supply: when a number of burners are suddenly extinguished or lighted, the indicator at the works immediately makes it known; this is effected by the small, but nicely-adjusted gasometer, connected with the main service; its rising and falling being the consequence of diminished or increased pressure within the main, the valves are either opened or shut, to allow the gas to pass or not from the gasometer. To this is attached a regulating rod, which has a pencil inserted in it, which in its motion is made to trace a line upon a ruled sheet of paper wrapped round a small cylinder; this is kept in regular rotation on its axis by means of machinery connected with the movement of a clock; thus during the night as well as day every change of pressure is indicated.

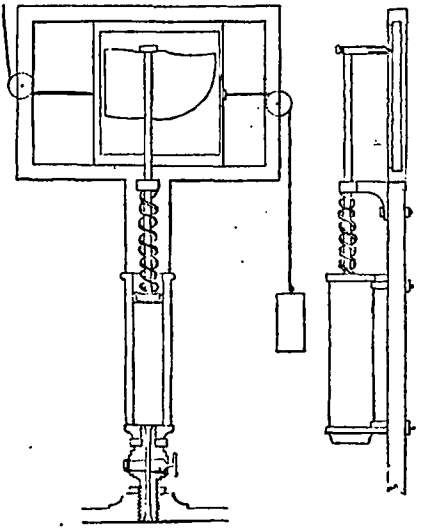


Fig. 1950. INDICATOR.

This invention of Mr. Crosley's for registering the actual pressure at the main outlet, and which indicates the most minute variations, with the precise times when they occur, enables a complete check to be kept against the person employed to superintend and regulate the supply. In the interior of the small gasometer is a small tube, which communicates with the main; an air-vessel within the gasometer occasions it to float when immersed in the water, at which time it is in a state of equilibrium with the external atmosphere; and as the gas in the main increases its pressure it rises, which rising is measured off by a scale, 12 inches in height, being equal to the pressure of a column of water 1½ inch in height. The paper by the horizontal lines shows every tenth of an inch pressure, and by vertical lines the hours when it occurs.

Sliding Valves are very simple, and are placed in an upright position, within a strong iron frame; they are perfectly smooth, and the plate which slides up and down is sometimes of brass, properly ground, and made to fill up the groove, and rendered completely air-tight: it is moved up and down by a screw, which turns in a socket formed on the upper part of the frame; but where their dimensions are considerable, a rack and pinion may be advantageously employed.

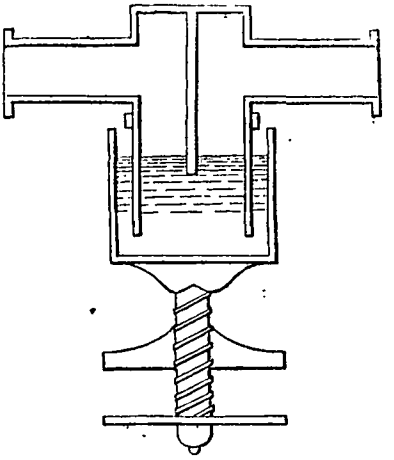


Fig. 1951. QUICKSILVER VALVE.

A Quicksilver Valve is sometimes used, formed by a square iron box, with a perpendicular division in it, which can be made to dip into another iron box below it, and in which a quantity of quicksilver is placed: into the sides of the upper box are inserted the two pipes to allow of the passage of the gas, when it is required; it is obvious that when the division of the upper box does not dip in the quicksilver, the

gas will freely pass under it, and proceed to the opposite pipe; when it is desired to shut off the communication, all that is necessary is to turn the screw beneath the bottom box, which works in a fixed female screw, and this so elevates the quicksilver that it closes, by the dipping of the perpendicular partition into it, all communication between the two horizontal pipes. The lower box has an iron rim round it, to preserve its regular motion, and to prevent it from moving otherwise than in an upright position.

Construction of Burners, Length of Flame, &c. — The burners are of several varieties. The *beak* is perforated with one small hole, $\frac{1}{25}$ of an inch in diameter, made perfectly round and smooth.

The *Argand burner* has the holes around a circle, and great care is required to place them at equal distances, as well as make them all equal in diameter; for when several jets issue from one burner, they should unite to form one flame. The distance at which the holes should be bored should be from 16 to 18 hundredth parts of an inch, or $\frac{1}{8}$ of an inch; and when the Argand burner has ten holes in the circumference and one in the middle, the central one should be made $\frac{1}{15}$ of an inch; and when twenty-five holes, that in the middle must be 1 inch in diameter. If the holes are too large, the gas will flow so rapidly that it will not mix proportionately with the atmospheric air and render its combustion complete; this affects the brilliancy of the light, and produces a quantity of smoke: when the holes are too small, the gas will not flow in sufficient quantity to produce the necessary quantity of light; and it is generally observed, that the burners which contain the greatest number of holes within a certain space afford the most brilliant light.

The Argand burner being composed of a ring, the centre part is left open for the admission of a supply of atmospheric air to the interior of the flame, and by means of a glass chimney the combustion of the gas is rendered more complete, as well as more active: those burners which have 10, 15, 20, or 25 holes, have their diameters $\frac{8}{10}$, $\frac{1}{2}$, $\frac{6}{10}$, and $\frac{24}{100}$ of an inch; the breadth of the rim $\frac{12}{100}$ of an inch, and the length of the burner $1\frac{1}{4}$ inch.

The height to which flame may be raised without smoking is in this proportion: with eight holes, 4 inches; ten holes, $3\frac{1}{2}$ inches; fifteen and twenty, $2\frac{1}{2}$; and twenty five, 2 inches; and it is a singular circumstance, that all these burners emit the same quantity of light.

The most economical as well as the most brilliant light is afforded when the jet-holes are very numerous, the air aperture small, and the chimney narrow: when several jets are united, as in the Argand burner, the light increases in a greater ratio than the expenditure of the gas. The glass chimneys for the burners mentioned should be 8, 12, 13, and 15 tenths of an inch in diameter, and 6 inches in height.

The luminous quality of gas depends upon the portion of carbon held in solution by the hydrogen, and also upon the quantity of oxygen which each may require for its perfect combustion, according to its volume, and the intensity or measure of the light produced is ascertained by the faintness or blackness of the shadows, when an opaque object is placed between the light and a sheet of white paper. Light always moves in straight lines, and diverges in all directions, its intensity decreasing in proportion with the square of the distance; thus at the distance of 1, 2, 3, or 4 yards, its intensity will be diminished in proportion to the square of those numbers, or as 1, 4, 9, 16, so that at the distance of 2 yards the light will be only $\frac{1}{4}$ what it was at 1 yard distance, and when at 3 yards, 9 times less, and at four, 16. Dr. Priestley found that when two lights shone upon the same surface at equal obliquities and an opaque body was interposed, the two shadows produced differed in blackness or intensity in a similar degree: the shadow produced by intercepting the greater light being illumined by the lesser only, the other shadow would be less intense, and the strongest light would have the deepest shadow. Thus when two lights are to be compared, they should be so placed that a ray from each should fall with nearly the same angle of incidence upon the middle of a sheet of paper; by interposing some opaque object the two shadows it occasions may be made to lap over each other; then if the lights are removed or brought nearer the paper, until all the shadows are of the same intensity, it will be found that the quantity of light emitted by each will be as the squares of the distances from the paper. Colour has something to do in the comparison of the intensity of two lights, that flame which is nearest to a pure white being the most brilliant, and its lustre diminishes in its approach to a brown hue, and this often affects the appearance of the shadows thrown for the purpose of estimating the quantity of light.

To ascertain the purity of coal gas it is only necessary to pass it over a solution of acetate of lead: this may be done by unscrewing the burner, and then in lieu of it screwing on a bent tube, which, if allowed to dip its end into this solution, will at once indicate whether there is any sulphuretted hydrogen remaining, by the solution becoming dusky or a black precipitate, but if it do not change its colour you may be satisfied the gas is perfectly pure.

Litmus paper dipped in water is a good test for sulphuretted hydrogen: the dark purplish blue, if this gas be present, changes its colour to red; if carbonic acid be present, by adding a little lime water to it, an effervescence will take place when a few drops of muriatic acid are added. Hydrogen gas affects both silver and mercury; on mercury it produces a black film, and it soon tarnishes the other metal.

Six tallow mould-candles, weighing a pound, will burn forty hours, if lighted in succession; a gallon of sperm oil, burnt during the same time, will give a light equal to 15 such candles; 500 cubic inches of coal gas give a light for an hour equal to one of the above candles, so that it would require 20,000 cubic inches to be equivalent to the 6 mould candles, or between 11 and 12 cubic feet of gas; the cost of which is estimated at about 1½*d.* per cube foot, as delivered for burning.

Oil Gas is generally admitted to be more pure than that made from coal, and the process for its manufacture is very simple: a furnace is provided to heat the retort red-hot, the front of which is a cylindrical cast-iron vessel, with a cover fitted to its mouth, so as to close it completely: the retort is partly filled with coke and broken brick, so that the oil, which falls by drops upon the heated substance, may be exposed to as large a heated surface as possible. The oil is contained in a copper vessel, and permitted to drop regularly through a pipe upon the heated matter in the retort, where it is decomposed, after which the gases ascend into the cistern or condenser above, formed of two iron vessels, one within the other, and the space between is filled with cold water, for the purpose of condensing the products of distillation.

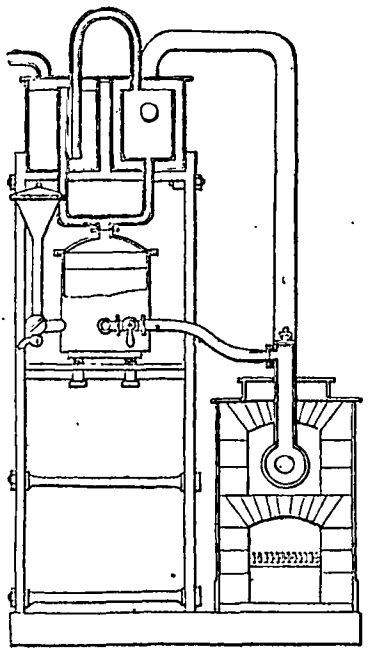


Fig. 1952. OIL GAS.

Mr. Beale has contrived an apparatus for the production of a powerful light, by the consumption of the refuse tar of the gas-works: it consists of an external copper case, at the bottom of which is a cock to discharge the fluid, should it rise above the required level. The tar is placed in the cylinder, and allowed to mount in the pipe attached, which it does by the pressure of the atmosphere, on the principle of the Argand lamp; at the bottom of the pipe is another, connected with a vessel, in which air is contained under a pressure of 1¼ pound per square inch: this by means of a small cock can be opened or shut at pleasure. When the tar is lighted, a small lambent flame is first obtained, and when the compressed air is admitted, it burns with a strong vivid white light.

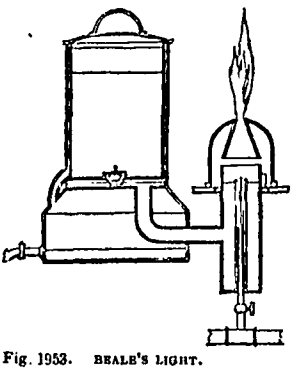


Fig. 1953. BEALE'S LIGHT.

CHAP. XXI.

STEAM CONSIDERED AS A MOVING POWER.

From the elasticity of steam, which arises from the latent heat it contains, very early advantage was taken of its power, and it is now universally applied for the purpose of moving and impelling machinery: like all gaseous fluids, if steam be separated from the

fluid which generates it, it does not possess a greater quantity of elastic force than the same quantity of air. The latent heat of steam may be taken at about 950°; steam at the temperature of 212° contains 900° of heat, which is not detected by the thermometer in its gaseous state, so that the real quantity of heat may be taken at 950° added to 212°, or 1162°. If a quantity of steam be mixed with 5½ times its weight of water, at 32° of temperature, the water will rise nearly to the boiling point: when water is boiled, its temperature never rises above 212°, nor does the steam which is produced; the only effect is in the more abundant supply of vapour, but if the water be confined in the vessel in which it is boiled, it as well as the steam may be brought to almost any temperature.

Steam Engine.—The high-pressure and the low-pressure are the two kinds in ordinary use; the first is simple and composed of few parts, and well adapted for locomotive engines, and other purposes where economy and portability are a consideration: the low-pressure engine is, however, not only more durable, but consumes less fuel, and is the most efficient for all ordinary purposes. The high-pressure engine is sometimes called the non-condensing, to distinguish it from the low-pressure engine, which is called the condensing; sometimes in one engine the properties of both are combined. The high-pressure engine now in use, the principles of which are more elementary and simple, was not brought into practice until long after Mr. Watt had perfected the other.

High-pressure steam is produced by confining it within the boiler and increasing its temperature and strength to a greater degree. The force of such steam is thus estimated: a pound weight is placed upon a hole on the top of the boiler, exactly an inch square; when the steam is powerful enough to lift the weight off the aperture on which it rests, its power is said to be one pound on the square inch: by placing a greater weight, a greater elastic pressure is produced, and 1000 pounds on an inch have been measured by this means. The ordinary pressure given to engines of this kind varies from 15 to 120 pounds per square inch: when 15 pounds is the pressure, it is called one atmosphere, or high-pressure steam of the elastic force of one atmosphere: 6 pounds of coals, employed in converting 6 gallons of water into steam, is equal in power to the labour of a man for an entire day.

One of the simplest forms of application of high-pressure steam for the raising of weights is by conducting the steam through a cylindrical tube, into which is inserted a movable piston, on the top of which is placed a weight: when the steam issues from the boiler, and passing under the piston, is strong enough to overcome the weight, the piston will rise to any required height; if the weight be equal to one atmosphere, and the area of the piston equal to a square inch, any increase in the pressure of the steam beyond one atmosphere of elastic force will raise the weight.

The Atmospheric Engine is not worked by the direct and immediate agency of steam, but by the atmosphere: the steam is here used only to make way for the atmosphere, and give effect to its pressure. Engines of this description are usually constructed to condense the steam in their own cylinders, and are used for either raising water or coals: in construction they are simple, but when their cylinders are less than 24 inches in diameter, the consumption of fuel is considerably above the effect produced. In forming the cylinder it is usual to make its diameter half its length, and the velocity should be about 98 times the square root of the length of the stroke in feet per minute. The area of the steam passages is, as 4800, is to the velocity in feet per minute, so is the area of the cylinder, to the area of the steam passage. The number of cube feet of water required per minute for steam is found by multiplying the number of feet contained in the area of the cylinder, by half the velocity in feet, and that product by 1·23 added to 1·4, divided by the diameter in feet, and that quotient again divided by 1480. Twelve times the quantity of water required for the purposes of steam is necessary for its condensation, and the aperture by which it is injected should admit that quantity at every stroke that is made. The area of the jet aperture should be the 850th part of the area of the cylinder, and the conducting pipe four times the diameter of the jet.

To ascertain the power of an atmospheric engine, multiply 5·9 times the square of the diameter of the cylinder in inches, by half the velocity of the piston in feet per minute; the product so obtained expresses the effective power, or the number of pounds elevated a foot high per minute; the horse-power is found by dividing by 33000. In a cylinder with a diameter 72 inches, length of stroke 9 feet, and making 9 strokes per minute, it will be shown by $9 \times 9 = 81$; then $5{\cdot}9 \times 72 \times 72 \times 81 = 2477433{\cdot}6$ lbs. raised a foot per minute, or 75 horse-power.

In the ordinary atmospheric engine, when the condensation takes place in the cylinder, it is closed at the bottom and open at top, as represented at C: at S is a passage for the steam at the bottom of the cylinder, with a valve or cock at V: at I is the passage for the cold water, which condenses the steam, with a cock at D: at E is the passage for the water which has been injected to run out; this passage has a valve

at F, which prevents its flowing back again: at G is a valve for the air to escape. The engine beam has attached to it mechanism which opens and closes the valves; and water is supplied at the top of the piston to make the packing around it steam-tight. When the beam is in the proper position, steam is admitted below the piston by the valve V: this valve is then, by the action of the beam, shut off, and the injection cock at D opened; water then flows through the pipe at I, and condenses the steam within the cylinder, after which it passes off through the pipe E; the atmosphere then acting on the piston, P, it is forced down, the air contained in the cylinder, and produced by the condensation of the water, being suffered to escape at G: connected with the beam is a bar having a vertical movement; in this is attached lappets, which open the steam and injection cocks or valves: the steam-valve closing, and the injection cock opening when the up-stroke is completed, the steam-valve is made to open with the rise of the piston.

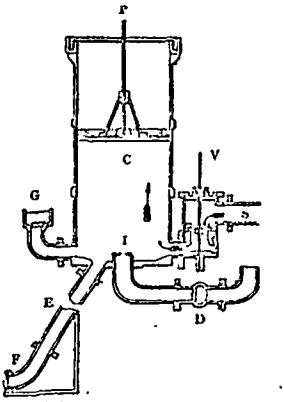


Fig. 1954. COMMON ATMOSPHERIC.

This kind of engine may be regulated by turning off the steam, and cutting off the injection: a hot well supplies the water for the boiler, and about 16 pounds of coal per hour for each horse-power is the quantity required to work it; the boiler, whatever its form, should have the steam limited to 1 pound on the circular inch.

When this kind of engine has a separate condenser, it is constructed as shown in fig. 1955.; the steam is admitted by the pipe S, through the slide B, into the cylinder at D; A is a pump with a solid piston, which expels the condensed steam, air, and water, the injection being made into the pipe E; I is the injection cock; F is a cock to let out any air that may accumulate when the engine is not at work, below the piston P.

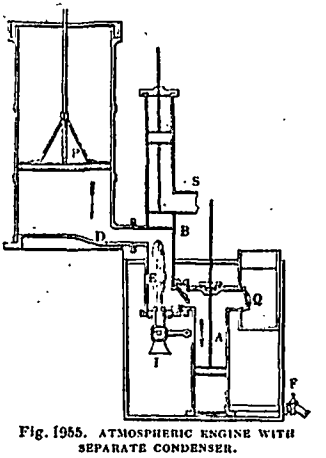


Fig. 1955. ATMOSPHERIC ENGINE WITH SEPARATE CONDENSER.

When it is required to set the engine to work, the slide B is raised above S, and sufficient steam is admitted to drive out the air at the valve Q, the pistons, both of the cylinders and pump, being up: the steam is then shut off by the slide B, and the injection opened, when, in consequence of the condensation which takes place, both pistons descend, during which the cock F must be opened, and then closed: the injection being stopped, the slide B closes the opening to the condenser, and by again admitting the steam, the pistons rise, and the air and water are driven out at Q; by opening and closing these passages alternately, the action is continued: by closing the valve B during the ascent, and the cock I during the descent, the engine may be regulated: the power of the atmospheric engine, when applied to raising water, should have its velocity in feet per minute 98 times the square root of the length of the stroke, and the diameter of the cylinder should be half its length. The area of the steam passages should be to the area of the cylinder, as the velocity of feet per minute is to 4800: the stroke of the air-pump should be half that of the piston, and its diameter three-eighths that of the cylinder.

To ascertain the quantity of steam, multiply the number of feet contained in the area of the cylinder by half the velocity in feet, with the addition of one-fifth of loss for cooling; this result divided by 1480 gives the quantity of water requisite to supply the boiler; and for injection, twenty-four times that quantity will be required. The aperture by which the injection is made should have its diameter one-thirty-sixth that of the cylinder, and the pipe one-ninth.

The power of the engine is found by multiplying 6·25 times the square of the diameter of the piston by half the velocity in feet per minute, and the product is the effective power in pounds raised one foot high per minute; this divided by 33,000 gives the horse-power. The cylinder being 32 inches in diameter, and the velocity 220 feet per minute, we have $6{\cdot}25 \times 32^2 \times 110 = 704{,}000$ pounds, or 21 horse-power; 29·4 feet of water is required per hour, and 246 lbs. of caking coal, or 11·7 lbs. for each horse-power,

Steam Pressure Engines. — *Boulton and Watt's Single Engine*, as applied to the raising of water. The boiler is surrounded with brickwork, and the steam passes by the pipe *b* to

the cylinder, which is securely fixed to the floor; a lid at *e* covers the top; through this slides the piston-rod in an air-tight stuffing-box; the beam moves on its gudgeons, the bearings for which are properly sustained: a pump-rod carrying a counter-weight is suspended at the end of the beam at *g*, and both it and the piston rod *k* are connected by a parallel motion to the working beam, *fg*: at *m* is the condensing cistern, which con-

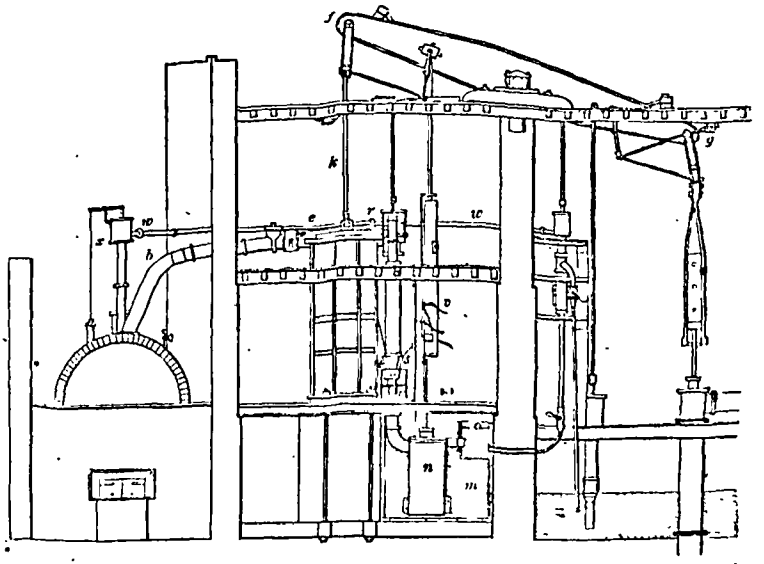


Fig. 1956. BOULTON AND WATT'S SINGLE-ACTING ENGINE.

tains the air-pump, *n*, the condenser and hot well, *o*. By the action of the cold water pump, a continued supply is obtained, and all excess is carried away to the well by the waste-pipe: *r* is the upper steam valve, *s* the lower one, *t* the exhausting valve; these are all opened by the plug tree, *v*, and the lappets with which it is furnished. Water is raised from the hot well, *o*, by the pump, to supply the boiler, and is carried by a pipe, *w w*, into a small cistern, *x*, on the top of the feed-pipe, which has a valve, acted on by a lever, attached to a wire passing through the stuffing-box to a stone float in the boiler, which opens the valve by its descent, and permits an additional quantity of water to flow in when required.

The Single-acting Engine differs from the double in the arrangement of its pipes and valves, as shown in fig. 1959.: the steam is condensed into the state of water: the moving force equals the power of the steam: there are two cylinders; one admits the steam at the top, and another, called the condenser, admits the steam at the bottom, from the lower part of which is the passage to the air-pump. The cylinder in which the piston works is shown at C, the condenser at B, and the air-pump at A: by the pipe S the steam passes from the boiler through a valve at O, by which the piston, P, is forced down; the steam which is beneath it passes into the condenser, the bucket, *p*, of the air-pump descending at the same time: the rod O receives a motion when the piston has arrived at the bottom of the cylinder, which opens the valve *b*, and shuts those of *a* and *c*. The pipe E has then a communication with both the bottom and top of the cylinder: the jet is stopped, and the cylinder and condenser again filled with steam from the boiler; the piston is raised by a counterweight to the top of the cylinder; this counterweight is applied to the opposite end of the beam to that on which the piston-rod is fixed: when the cock is open, which allows the steam to pass from the boiler into the cylinder, the steam in the condenser, and below the piston of the cylinder, is, by the playing of the jet of cold water into it, reduced to water; when the pressure on the top of the piston being equal to the force of the steam in the boiler, and that below being small, the piston is pressed down, and thus raises an equivalent weight at the opposite end of the beam.

The passage to the condenser is shut off when the piston reaches the bottom of the cylinder; a valve in the piston then opens, and allows the steam to pass through it: the piston rises by the action of the weight placed on the opposite end of the beam.

When the piston is at the top this valve closes, and that of the condenser opens.

The air-pump during this and the succeeding operations is worked by the beam, and at each stroke of the piston makes a simultaneous movement, and thus is enabled to pump out the air and water which is the result of each condensing operation. G is a foot-valve between the condenser and the air-pump, M, which has a discharge valve at Q, through which the air and hot water are forced into the hot well, shown at K: a pipe at N constantly supplies the cistern which contains the condenser and air-pump with cold water. The condenser has a flow valve at H: at the end of a pipe is a rose, which admits the jet, through which the cold water passes into B, and this is forced into it, and made to spread through the steam as much as possible, for the purpose of speedily condensing it.

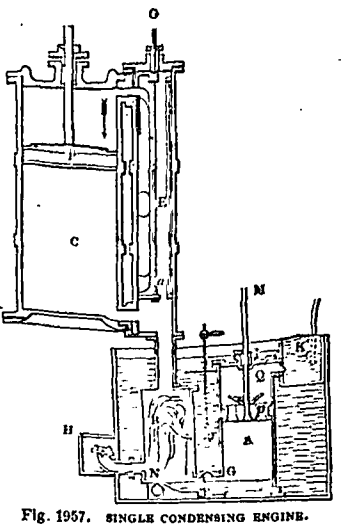


Fig. 1957. SINGLE CONDENSING ENGINE.

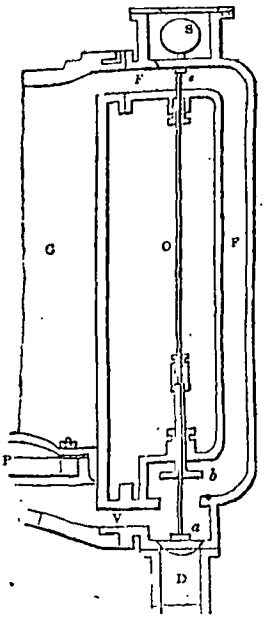


Fig. 1958.

The diameter of the cylinder should be half its height, and the velocity of the piston in feet per minute ninety-eight times the square root of the length of the stroke: the steam passages should be equal to the area of the cylinder multiplied by the velocity of the piston per minute, and divided by 4800. The air-pump should have half the diameter, and half the length of stroke of the cylinder, or should be one-eighth of the dimensions of the cylinder, and the condenser should be equal to it. The quantity of steam is ascertained by multiplying the number of feet contained in the area of the cylinder by half the velocity in feet, adding one-tenth for waste; this, divided by the column of steam of equal force to that contained in the boiler, gives the quantity of water required per minute for the creation of steam, from whence the proportions given to the boiler are established: with the pressure of two pounds per circular inch on the valve, the divisor will be 1497. The water for the purposes of injection will be twenty-four times that required for steam; consequently the diameter of the pipe used for this purpose must be about a thirty-sixth of the diameter of the cylinder: usually the force of the steam in the boiler equals 35 inches of mercury, that of the steam in an uncondensed state 3·7 inches. To find the effective power of such an engine, or the number of pounds raised a foot high per minute, multiply 6·66 (which expresses the number of pounds of the mean effective pressure on the piston) by the square of the diameter of the piston in inches, and by half the velocity in feet per minute: the product is the effective power; this divided by 33000 gives the horse-power.

Double-acting Steam Engine. — The steam cylinder is enclosed in a jacket or casing of cast-iron, a trifle larger than the cylinder, and the space between them is supplied with steam, to keep the temperature of the cylinder as near to that of the steam as possible. The working beam is supported by a cast-iron column, and is connected to the piston-rod by the parallel motion: the other end of the beam gives a rotary motion to the crank shafts, by means of a connecting rod, the lower part of which is attached to the crank. The steam enters at S, passes through the top valve, and acting on the piston forces it down; before it arrives at the bottom of the cylinder, the plug on the rod R comes in contact with a lever, shuts one valve, and opens another; the steam then continues its course down the pipe S, acts on the bottom of the piston, and forces it up to the top of the cylinder, while the steam, which forced it down, escapes into the condenser B, where it meets with a jet of cold water, is condensed, and then cleared away by the action of the air-pump A, which is worked by the rod R. The cistern is supplied with

cold water by the pump N; the governor, put in motion by bevelled wheels on the shaft of the fly-wheel P, regulates the throttle-valve in the steam-pipe S: in the pumping apparatus, the rod M is the pump-rod for raising water; when the rod descends, the water will be forced through G into the upper air-vessel E, from whence it passes to the reservoir,

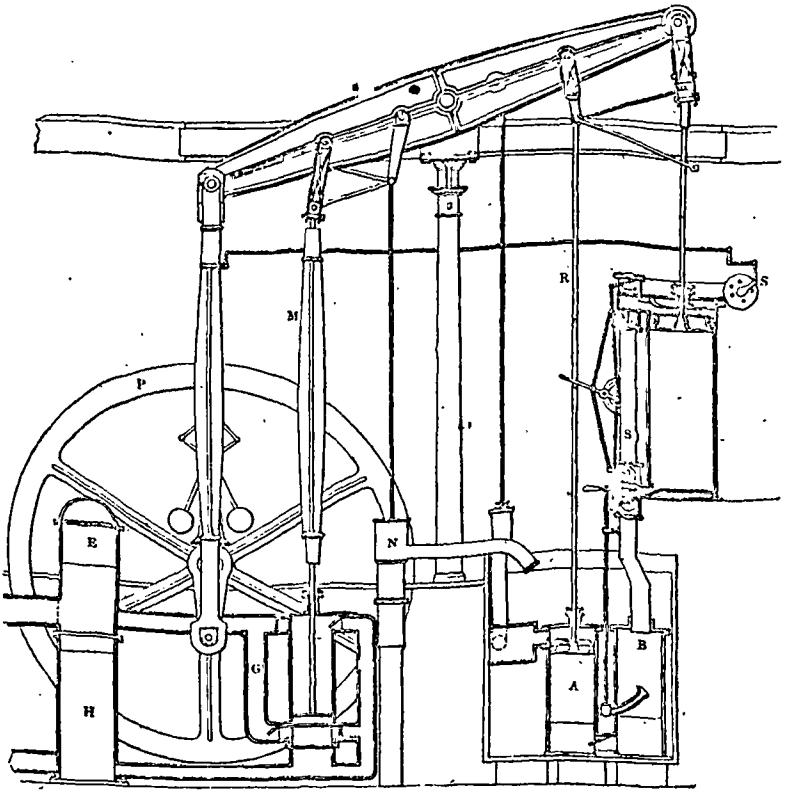


Fig. 1959. DOUBLE-ACTING ENGINE.

at a distance and height proportionate to the power of the engine: the barrel of the pump is refilled from the pipe F, which communicates with the lower air-vessel H.

The Double-acting Engine of Boulton and Watt (fig. 1962.) differs from that already described, by having a passage from the boiler, both at the top and bottom of the cylinder, and similar communications from both to the condenser: the counter-weight at the end of the beam is not here required to raise the piston. The force of the steam impels the piston both upwards and downwards, and a double power in the same space and time is obtained by the use of a double quantity of steam: the steam enters the cylinder at S, passing by F into the upper, and by D into the lower part: through D the steam escapes into the condenser B, and during the ascending stroke, the uncondensed gases and water escape by the valve G; when descending, they pass through the valve of the pump-bucket, and at the ascending stroke are driven out at the valve Q into the hot well. The steam passes through F, down the pipe E, to the condenser, from the upper portion of the cylinder; during the time the piston P is in the action of ascent, D slides open and closes the passages at D and F, through the means of the rod O. The diameter of the cylinder should be half its height; the velocity of the piston in feet per minute is found by multiplying the square root of the length of the stroke by 103 for machinery, or by 98 for raising water. The area of the cylinder multiplied by the velocity of the piston in feet per minute, divided by 4800, gives the area of the steam passages. The air-pump should have half the diameter of the cylinder, and half the length of stroke, or one-eighth of the capacity of the cylinder, and the condenser should be equal to it. The area

of the cylinder in feet multiplied by the velocity in feet, with the addition of one-tenth for waste, gives the quantity of steam; and this again divided by the volume of steam gives the quantity of water required per minute for steam: the proportions of the boiler may then be determined; at the common pressure of two pounds per circular inch on the valve, the divisor will be 1497. The water for injection must be 24 times that required for steam; and the diameter of the injection-pipe made one-36th that of the cylinder. The effective power of such an engine is found by multiplying the effective pressure on the piston by the square of its diameter in inches, and that product by the velocity in feet per minute: the quantity of pounds raised one foot high per minute being obtained, and divided by 33000, gives the horse-power, and each horse-power requires a supply of 9·2 lbs. of coal per hour; but when the engine is less than ten horse, the quantity required is increased: such an engine is applicable to all purposes, and when steam is made to act expansively, the power is obtained with less fuel; when so applied, a fly-wheel equalises its motion. Fig. 1961. shows the steam shut off, and the passage to the condenser still open. Fig. 1960. represents its state when steam is let on at the bottom: the letters refer to corresponding portions of fig. 1962.

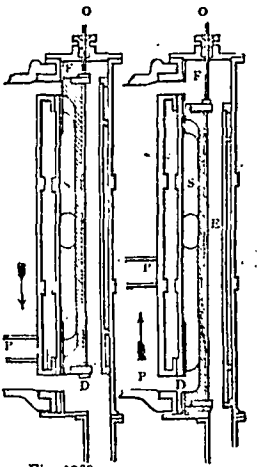


Fig. 1960. Fig. 1961.

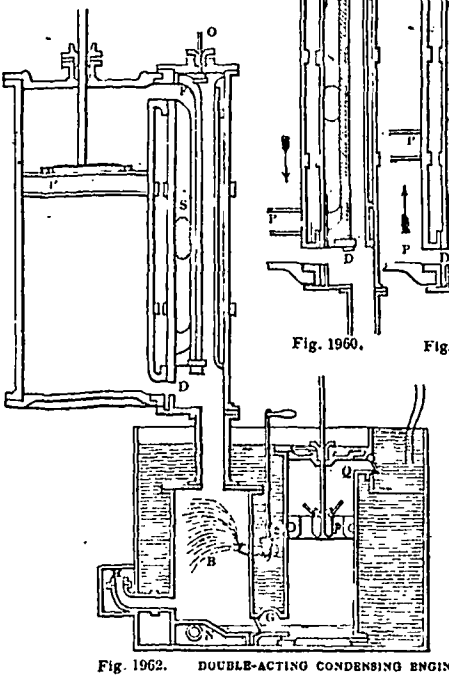


Fig. 1962. DOUBLE-ACTING CONDENSING ENGINE.

One of the earliest engines with a double-action was made by Mr. Watt, in 1782, and some years afterwards two of fifty-horse power each were put up at the Albion Mills, Blackfriars, which jointly drove 20 pair of mill-stones, of which 12 or more, with all the machinery for dressing the flour, were generally kept at work. In this engine (fig. 1963.), A is the cylinder, 34 inches in diameter; B, the piston, which has an 8-feet stroke; C, the piston-rod; D, the stuffing-box, or cover of the cylinder; E, the steam-case or jacket of the cylinder, from which a siphon empties the water, and which is supplied by a pipe; G, the upper steam nozzle and valve or regulator box and regulator; H, the upper exhaustion nozzle and valves; I, the perpendicular steam-pipe; J, the eduction-pipe; K, the lower steam nozzle and valve; L, the lower exhaustion nozzle and valves; M, the condenser, immersed in a cistern of cold water, the injection cock being always open during the working of the engine; O, the blow-valve; P, the air-pump; Q, the lower valve and air-pump; R, the bucket and rod of the air-pump; S, the upper valve of the air-pump; T, the hot water pump, with the bucket and rod; U, the cold water pump; V, the pump for supplying the boiler; W, the governor, turned by a belt from the shaft of the fly-wheel; X, the lever and rod, which connects the governor with the throttle valve *t*; Y, the working gear of the nozzle valves; Z, the plug-tree which drives the working gear; *a*, the main lever or working beam; *b*, its main gudgeon; *c*, the perpendicular links of the parallel motion; *d*, the parallel bars; *e*, the regulating radii; *f*, the small perpendicular links; *g*, the secondary parallel motion for the air-pump; *h*, the connecting rod; *i*, the planet-wheel fixed to the connecting rod; *j*, the iron wheel; *k*, the shaft of the fly-wheel, on which the iron wheel is fixed; *l*, the connecting link, which retains the planet-wheel in its orbit; *m*, the fly-wheel; *n*, the boiler; *o*, the tube through the boiler and the tube round it; *p*, the grate; *q*, the feeding mouth; *r*, the damper; *s*, the chimney; *t*, the feed-pipe; *u*, the gauge pipes, with the cocks; *v*, the safety-valve.

The boiler is generally made of iron, though formerly copper was used; and by means of a pipe the steam passes from the boiler to the upper nozzle G, and by the perpendi-

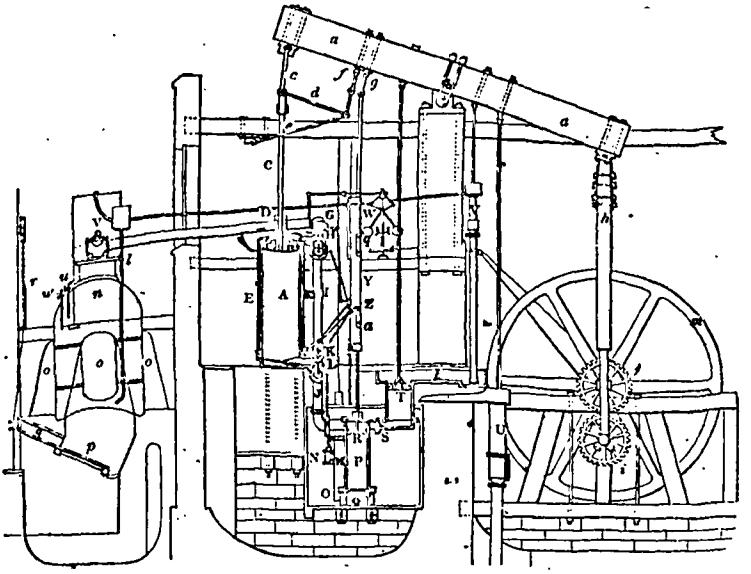


Fig. 1963. ENGINE AT THE ALBION MILLS.

cular steam-pipe I, to the lower steam nozzle K: in the nozzle G there is a valve, which when open admits steam into the cylinder above the piston B, through the horizontal square pipe at the top of the cylinder, and in the lower steam nozzle K there is another valve like that at D, which, when opened by the pin of the plug-tree, admits steam into the cylinder below the piston. In the upper exhaustion nozzle, H, there is a similar valve, which when open allows steam to pass from the cylinder above the piston into the eduction-pipe J, which conveys it to the condensing vessel M, where it meets with the jet of the injection from the cock N, and is reduced to water; and in the lower exhaustion nozzle L, there is also a valve, which when open allows the steam to pass out of the cylinder below the piston into the condenser M.

The engine being at rest, the cylinder quite cold, and the condenser cistern full of water, when the water in the boiler begins to boil, steam will enter by the small pipe *f* into the space between the cylinder and the heating case E, which will expel the air contained in that space, and between the two bottoms of the cylinder, at a cock fixed in the outer bottom, which, when all the air is expelled and the cylinder thoroughly warmed, is to be shut, and the water which may be formed in these spaces during the working of the engine will issue by the inverted siphon *e*.

The first operation after this state is to open all the four valves, G, H, K, L; the injection cock being shut, the steam will drive the air out of the pipes I and J, and out of the condenser M, through the blow-pipe and its valve O, and as soon as this is succeeded by a sharp crackling noise in the cistern O, the valves are to be shut, until it is thought that the steam which has entered is entirely condensed; the same operation is to be repeated, giving a longer time to cool between the times of blowing, until it is found upon opening the injection cock some water will enter, and the barometer shows some degree of exhaustion, after which the repetition of blowing will soon empty the cylinder of air. The piston being then at the top of the stroke, the valves G and L are to be opened, and the fly-wheel *m* turned by hand about ¼ of a revolution or more in the direction in which it is intended to move; the steam which is then in the cylinder will pass by L into the condenser, when, meeting with the jet of water from the injection cock, it will be converted into water, and the cylinder thus becoming exhausted, the steam entering by the valve G will press upon the piston, and cause it to descend, while by its action on the working beam, through the piston rod, it pulls down the cylinder end of the beam, and raises up the outer end, and the connecting rod *h*, which causes the planet-wheel *i* to tend to revolve round the sun-wheel *j*: but the former of these wheels being fixed upon the connecting rod, so that it cannot turn upon its own axis, and its teeth being engaged in those of the

sun-wheel, the latter and the fly-wheel, upon whose axle and shaft it is fixed, are made to revolve in the desired direction, and give motion to the mill-work.

As the piston descends, the plug-tree Z also descends, and a clamp or slider *q*, fixed upon the slide of the plug-tree, presses upon the handle I, of the upper shaft or axis, Y, and shuts the valves G and L; and by the same operation, by disengaging itself, permits a weight suspended to the arm of the lower Y shaft to turn the shaft upon its axis, and thereby to open the valves K and H. The moment previous to opening these valves, the piston reaches the lowest part of its stroke, and the cylinder above the piston is filled with steam; but as soon as H is opened, that steam rushes by the eduction-pipe J into the condenser, and the cylinder above the piston becomes exhausted; the steam from the boiler, entering by I and K, acts upon the lower side of the piston, and forces it to return to the top of the cylinder; when the cylinder is very near the upper termination of its stroke, another slider *a* raises the handle, and in so doing disengages the catch, which permits the upper Y shaft to revolve upon its own axis, and open the valves G and L, and the downward stroke recommences, as has been related.

When the piston descends, the buckets, R, S, of the air-pump and hot-water-pump T also descend; the water which is contained in these pumps passes through the valves of their buckets, and is drawn up and discharged by them through the trough *t*, by the next descending stroke of the piston: part of the water is raised up by the pump V, for the supply of the boiler, and the rest runs to waste. Engines of this kind, as described by Mr. Watt, were employed in producing rotary motions, but they were also used to work pumps by a reciprocating motion: for this purpose half of the pump-rods were suspended by means of a sloping rod from the working beam near the cylinder, and the other half were suspended directly from the outer end of that beam, so that the ascending motion of the piston pulls up one-half of these rods, and works the pumps to which they belong, while the descending motion of the pistons pulls up the other half of the rods, and works their pumps: such an engine was employed at Wheel Maid Mine in Cornwall; it had a cylinder of 63 inches in diameter, and 9 feet stroke; but the stroke in the pumps, which were 18 inches in diameter, was only 7 feet.

Mr. Watt gave the following account of the actual performance of one of his engines, working in the Cornish mines: — "One bushel of good Newcastle or Swansea coal in the reciprocating engine, working more or less expansively, was found to raise 24,000,000 to 32,000,000 pounds of water one foot high. In engines upon the rotative double construction, one having a cylinder of 31½ inches in diameter, and making seventeen strokes and a half of 7 feet long per minute, called forty-horse power, consumed about four bushels of Newcastle coal per hour, or four cwt. of Wednesbury coal. A rotative double engine with a cylinder of 23¾ inches in diameter, making twenty-one and a half strokes of 5 feet long per minute, was called twenty-horse power; and an engine with a cylinder of 17½ inches diameter, making twenty-five strokes of 5 feet long per minute, was called ten-horse power; and the consumption of coals was nearly proportionate to that of the forty-horse power: a bushel of Newcastle coals, which is the quantity a ten-horse engine consumes per hour, grinds and dresses about ten bushels of wheat.

Hornblower's Engine with two Cylinders, though it does not essentially differ from the one already described, displays much ingenuity: the chief parts are two cylinders, A, B, the largest of which is A; a piston moves in each, having their rods, C and D, moving through collars at E and F; these cylinders are supplied with steam by means of the square pipe G, which has a flanch to connect it with the rest of the steam-pipe; this square part branches off to both cylinders; *c* and *d* are two cocks, worked by the plug W by means of handles and tumblers: on the foreside of the cylinders is another communicating pipe, whose section is square or rectangular, having also two cocks, *a*, *b*: the pipe Y, immediately under the cock *b*, establishes a communication between the upper and lower parts of the small cylinder, B, by opening the cock *b*: there is a similar pipe on the other side of the cylinder, A, immediately under the cock *d*; when the cocks *c* and *a* are open, and the cocks *b* and *d* are shut, the steam from the boiler has free admission into the upper part of A, but the upper parts of each cylinder have no communication with their lower parts: from the bottom of the great cylinder proceeds the eduction pipe K, having a valve at its opening into the cylinder, which bends downwards, and is connected with the conical condenser, L. The condenser is fixed on a hollow box, M, on which stand the pumps N and O for extracting the air and water, which last runs along the trough T into the cistern U, from which it is raised by the pump V for recruiting the boiler, being already nearly at a temperature of 212°; immediately under the condenser is a spigot valve, at S, over which is a small jet pipe, reaching to the bend of the eduction pipe.

The cistern of cold water, R, contains the whole of the condensing apparatus; a small pipe P comes from the side of the condenser, and terminates at the bottom of the trough T, and is there covered with a valve Q, which is kept tight by the water that is always running over it; the pump-rods X cause the outer end of the beam to prepondorate, so

that when the engine is at rest, it is as represented. The cocks being all open and the steam issuing copiously from the boiler, and no condensation going on at L, the steam must drive out all the air, and at last follow it through the valve Q: on shutting the valves *b* and *d*, and opening the valve S of the condenser, condensation will immediately take place: at this time there is no pressure on the under side of the piston at A, and it immediately descends. The communication between the lower part of B and the upper part of A being open, the steam will go from B into the space left by the piston of A: it must therefore expand, its elasticity diminishing, and will no longer balance the pressure of the steam above the piston of B. This piston therefore, if not withheld by the beam, will descend until it is in equilibrio, having steam of equal density above and below it; but it cannot descend so far, for the cylinder A is wider than B: and the arm of the beam at which the piston hangs is longer than the arm which supports the piston of B; therefore when the piston of B has descended as far as the beam will permit it, the steam between the pistons occupies a larger space than it did when both pistons were at the tops of their cylinders; and its density as well as its elasticity diminishing as its bulk increases, it is no longer a balance for the steam on the upper side of B, which piston pulls at the beam with all the difference of their pressures: as the pistons descend, the steam that is between them grows continually rarer and less elastic, and both pistons pull the beam downwards.

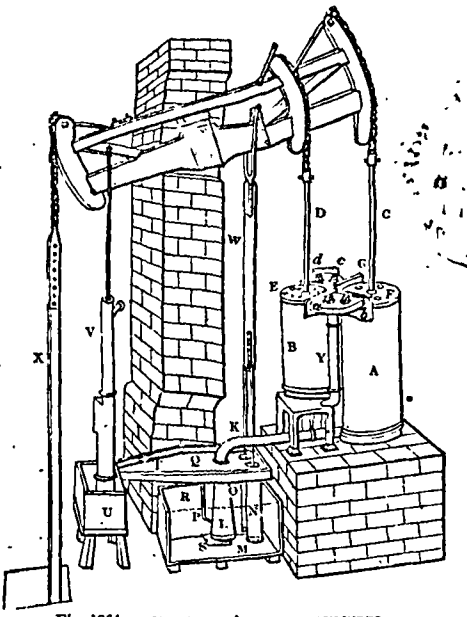


Fig. 1964. HORNBLOWER'S DOUBLE CYLINDER.

When each has reached the bottom of the cylinder, if the cock *a* and the eduction cock at the bottom of A be shut, and the cocks *b* and *d* be opened, the pistons will arrive at the top: the cylinder B is now filled with steam of the ordinary density, and the cylinder A with an equal absolute quantity of steam, but expanded into a larger space: on shutting the cocks *b* and *d*, and opening the cock *a*, and the eduction cock at the bottom of A, condensation will again be produced, and the pistons descend: thus the operation is continued. When both pistons are at the top of their cylinders the active pressure on the piston at B is nothing, while that on the piston of A is equal to the full pressure of the atmosphere on its area: this multiplied by the length of the arm by which it is supported gives its mechanical energy: as the pistons descend, the pressure on the piston of B increases, while that on the piston A diminishes; when both are at the bottom, the pressure on the piston of B is at its maximum.

Boilers.—Much yet appears to be wanting in practice to enable us to construct a perfect boiler, and science has not succeeded in determining the best form it should have: early in their application to the steam-engine, they were of a spherical shape, in consequence of that figure having the largest capacity with the least material; it was also fancied to be the strongest: a boiler of this form, placed upon an open fire, required a large quantity of fuel to raise a small quantity of steam, the heat being carried away by the surrounding air, and one of the first improvements was setting it in brickwork, or some non-conducting material that would bear the effect of the fire. The flues were so constructed that the flame, after passing below the sphere, wound round the sides in a spiral direction, and then passed off to the chimney, a damper being introduced to regulate the draught: this gave way to the cylindrical boiler, which was in a short time improved by making the top hemispherical, and arching the bottom upwards in order that a larger surface might be offered to the effects of the fire; the sides were inclined in such a way that the flame acted in a slight degree upon them.

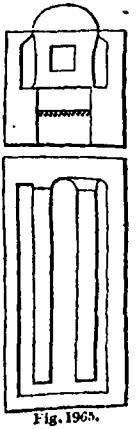


Fig. 1965.

The Waggon Boiler in its transverse section resembles that already described, but its length is much greater in proportion, and the sides are usually concave, that the flue constructed at their side may have more effect upon them. This form is in general use, and it is convenient, but not so strong, a small pressure having been found adequately sufficient to make these boilers bulge downwards and to press the sides outwards. To avoid these consequences strong iron stays are introduced within; they are applied in various ways, and have generally successfully resisted both compression and bulging.

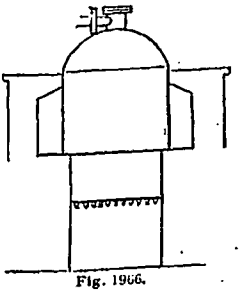


Fig. 1966.

The Cylindrical Boiler with hemispherical ends is one of the best forms, where safety and cheapness are considered; the flame is made to pass under it longitudinally, and heat its whole length: when it has arrived at the farthest end, hot air returns by means of a brick flue along one side, passes over the front end, returns along the other side, when it enters the chimney, after having traversed the whole length of the boiler three times: when space is not important, this form of boiler is highly valuable.

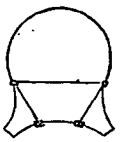


Fig. 1967.

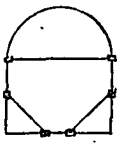


Fig. 1968.

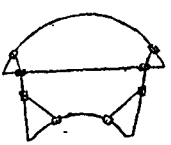


Fig. 1969.

The power of a boiler depends upon the extent of surface exposed to the action of the fire; heat passes through the boiler with a certain rapidity, and each square foot evaporates three-fifths of a gallon of water per hour: to boil off a cubic foot of water in that time will require 9 or 10 superficial feet of heating surface, and its quantity constitutes the power of 1-horse in the steam-engine; so that a boiler with 100 superficial feet exposed to the action of the flame will convert into steam 60 gallons of water in an hour, which is called a 10-horse power; the extent of heating surface, and not the contents of the boiler, measuring its power.

In the construction of a boiler regard must be had to the due adjustment and combination of all its parts, so that, while an extensive heating surface is obtained, any portion of it becoming damaged may be readily repaired: and the flues must be so formed that they can be readily got at and cleansed, and as much heat as possible obtained from the fuel, without the draught up the chimney being materially interfered with.

Boilers must be so capacious that the quantity of water to be boiled does not entirely fill them, but a sufficient space is left above its surface as a reservoir, for the steam as it is generated; if this were not provided for, the cylinder to be filled with steam might contain more than the volume of the boiler, so that it could not be regularly supplied, or with the speed necessary: when the boiler is made to contain five or six times the volume of the cylinder, one volume may pass off without any material change in the density of what remains, and the speed of the machine can be kept up: the water in the boiler must never rise above a certain level, and there should be sufficient quantity to produce steam, and protect the boiler from any injury from the fire. According to some writers, it should contain steam enough for eight or ten strokes of the engine, the quantity of water required for which is usually admitted into the boiler by a pump regulated by a float-ball; the temperature should be such that on its admission that of the steam is not reduced more than one-thirtieth, which is the case when the temperature of the water is reduced but two degrees; there ought to be in the boiler, then, about sixty-two times as much water as is introduced at one feed, or the elastic force of the steam will be lowered more than one-thirtieth: less water is required at a time, when the feeding apparatus acts frequently, and this should be introduced as hot as possible into the boiler; when fed at every stroke, 5 cubic feet of water should be allowed for every one of steam that it boils off in an hour: it is usual to allow 25 cubic feet of boiler for each horse-power, though this depends upon its form and application. The form usually given to boilers is rectangular, with a top consisting of the portion of a cylinder, the bottom a little concave, and the sides flat: in large boilers a flue passes through the middle, which is surrounded by water; they should always be constructed to consume as small a quantity of fuel as possible, and care should be taken that the air which passes through the fire shall part with all its heat before it escapes.

Rectangular Steam Boiler, with the top plate removed to show the internal arrangement: A, is the boiler; fire-door B; bars G; back F: the flames pass over F, under the bottom, rise at H and round I; then by another flue to the chimney at L, which is regulated by a damper at K: C is the ashpit, the door of which is made perfectly close, the air passing to the fire by the passage E, which enters by a grating at D: the pipe M N

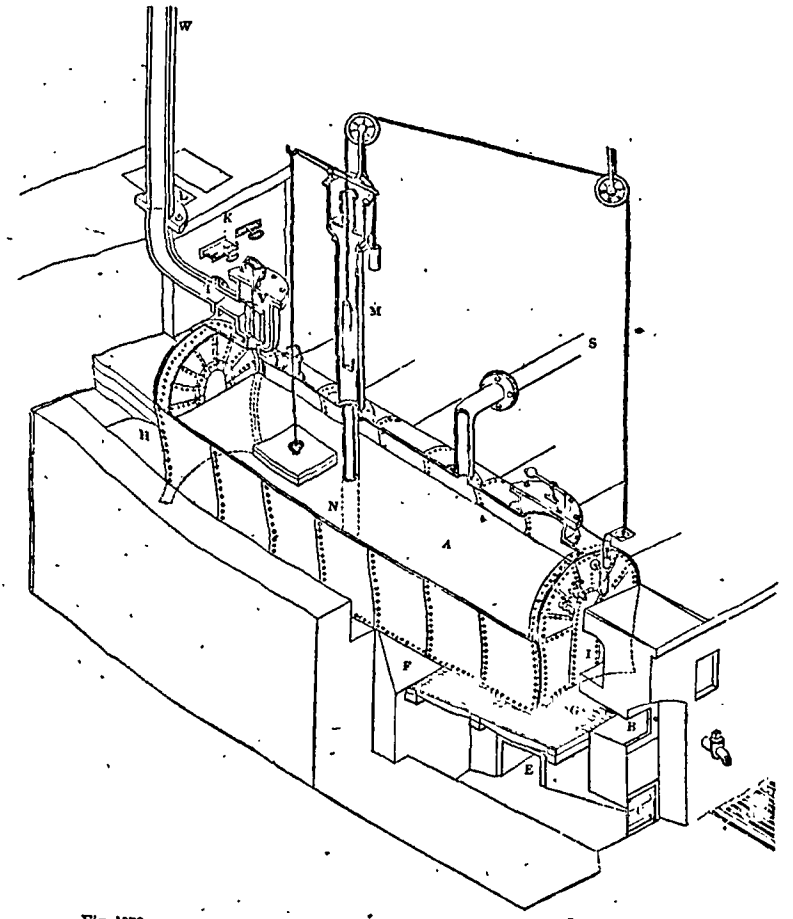


Fig. 1970. RECTANGULAR STEAM BOILER.

supplies the water; the steam passes to the engine by the pipe S, and when not required goes off through the safety-valve V, and through the pipes T, W.

To find the dimensions of a boiler without an internal flue, we must divide the solid content of the water it contains by the area of the bottom: we thus obtain the depth of water; then multiply the bottom and side surface for fire and flue, and divide the product by twice the capacity for water, less the area of the bottom surface, and the result will be one of the dimensions for the bottom; then divide the bottom surface by the dimensions found, which gives the other dimension. Cylindrical boilers, which are used for the production of high-pressure steam, may have their diameter and length found by adding their capacity for water and steam together, and also the quantity of surface for the action of the fire; then divide twice the capacity by the quantity of fire-surface for the diameter: the capacity multiplied by 1·27, and divided by the square of the diamoter, gives the length of the boiler.

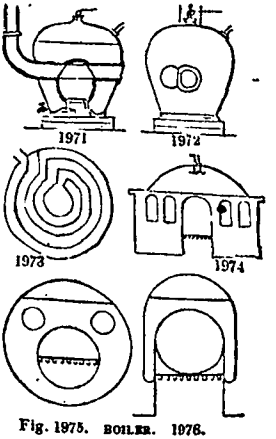


Fig. 1975. BOILER. 1976.

The Materials of which Boilers are usually made are either

iron or copper; cast-iron as well as wrought-iron plates are commonly applied; where fuel is abundant, cast-iron boilers, with proper care, have been extensively and advantageously employed. Copper, however, is decidedly the best of all substances for this purpose, cost being the only objection; one copper boiler will, however, probably endure as long as five or six iron ones, the uniformity of its texture at the same time insuring greater security against bursting, though its strength to resist flexure at high temperatures is not equal to that of iron; sheet-iron is liable to vary materially in its structure, although manufactured by the same process. The pressure which occasions the bursting of a boiler is proportional to the load on its safety-valve; that to crush it together is equal to the power of the atmosphere: the boiler should always be of such a strength that when in a working state, it will bear three times the pressure of what is on the valve; in low-pressure this may be too much, but in high-pressure boilers it is insufficient.

Copper loses 5 per cent. of its strength between the temperature of freezing and boiling water; at 550° a quarter of its strength; at 850° it loses one-half; and at 1330° it is entirely lost, becoming an incohesive substance, although it does not totally melt till it reaches 2000°. Iron plate, on the contrary, increases in strength, for at a temperature of 550° it is 16 per cent. stronger than when cold: after this point its strength rapidly diminishes, so that its maximum of strength does not certainly exceed 570°. The specific gravity of iron boiler plates is said to be about 7·7344, and by repeated piling and welding a great increase of strength may be obtained: the greatest practical strength is only to be taken at one-sixth of the absolute cohesion; and to prevent explosion, we ought to have four times the strength that any boiler is ordinarily worked at; 2500 pounds of extension on each square inch of cohesive action is the safe working strain for those made of iron.

To ascertain the thickness of the boiler plates made of any of the ductile metals the following rules are given: for the upper plates, when of iron, multiply the load in pounds per circular inch on the safety-valve, by the greatest diagonal of the section in inches, and divide the product by 120 times the cubic contents of the boiler per horse-power; the result is the thickness in inches: when the plates are copper, divide by 72 instead of 120; it is usual to increase the thickness of the bottom plates to about one and a half times those of the upper. For spherical boilers, of malleable iron, multiply the diameter in inches by the pressure on the valve in pounds per circular inch, and divide by 240 times the cubic contents of the boiler for each horse-power. For copper, divide by 144, instead of 240. When cast-iron is used, its unequal expansion must be taken into account; and for the strength of tubes exceeding 8 inches in diameter, multiply the square of the diameter by the pressure on the safety-valve in pounds on a circular inch, and divide the product by 150 times the cubic feet of space in the boiler per horse power, multiplied by the difference between the diameter and 7·4 inches; the result is the thickness in inches that should be given, together with some increase for wear and tear: thus, with a tube the internal diameter of which is 10 inches, the cubic feet of the boiler per horse-power being 10, and the load on the safety-valve 86 pounds on the circular inch, its thickness will be found to be ·92 inches: when the thickness is greater, the risk from unequal expansion increases; and when less, failure may result from the effect of pressure and inequalities in the iron itself.

The Piston Gauge is a small tube 2 inches in diameter; the cylinder has a solid plug turned and ground, to set loosely in it, the pressure of the steam bearing up the piston on the level, one end of which, attached to the spring indicator, gives the pressure of the piston.

Mercurial Gauges of various kinds are applied to the crowns

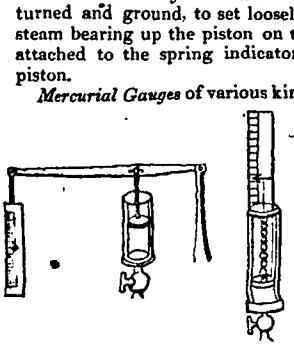


Fig. 1977. PISTON GAUGE. 1978.

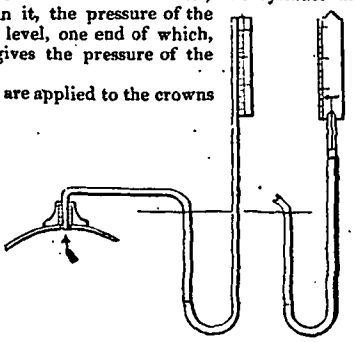


Fig. 1979. MERCURIAL GAUGE.

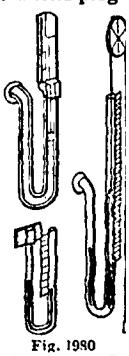


Fig. 1980 DYNAMOMETER.

of boilers, which, by means of a graduated scale above, mark off the pressure at all times exerted by the steam.

The Dynamometer, employed to measure the force of steam in the boiler, is a simple bent tube, of glass or iron, in the form of the letter U, the two ends of which are curved; one is applied to the boiler, and placed in communication with the steam: half the tube is filled with mercury, which rises and falls according to the pressure exerted on it.

Water Gauge is an instrument attached to the steam-engine boiler for the purpose of regulating the quantity of water and fuel, as well as the combustion and elasticity of the steam.

The Glass Gauge attached to steam-engine boilers is either of flat or tubular glass: the first description consists of a small window, made of very thick glass, inserted in the boiler, at the place up to which the water should rise.

The Tubular Glass Gauge is a small pipe of glass, about ½ inch in diameter internally, and 1¼ inches thick: it is placed outside the boiler, and communicates at the top and bottom by stopcocks with the interior of the boiler: the higher stopcock enters where the steam is a little above the surface of the water, so that the water, standing in the glass tube on the same level with the water in the boiler, is shown to the attendant.

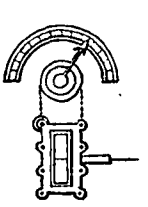


Fig. 1981. WINDOW GLASS GAUGE.

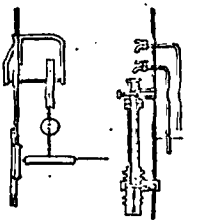


Fig. 1982. TUBE GLASS GAUGE.

Feeding Apparatus for Boilers is for the purpose of supplying it with water, in lieu of that passing off continually as steam: a simple form, adapted to a low-pressure engine, may have the water conducted into the reservoir of about 18 inches diameter, with a pipe to conduct from it into the boiler: the top of this pipe may be closed by a conical plug, hanging at the end of a rod V*r*, from a lever supported at *f*, and having two weights W and *u*; that of W rests on the surface of the water in the boiler, which falls whenever the water is below its proper level. The arm L is pulled down by the rod L W, which passes through a steam-tight stuffing-box; by the same motion the lever L ascends and opens the valve V, and allows the water to descend to replenish the boiler.

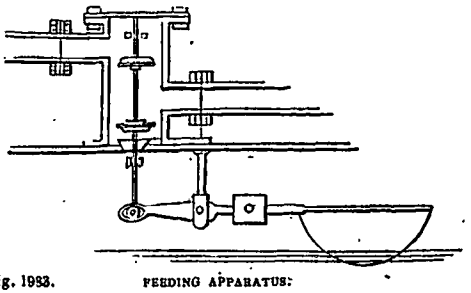


Fig. 1983. FEEDING APPARATUS.

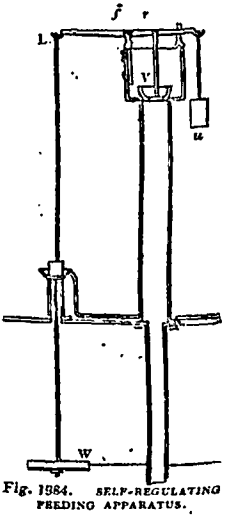


Fig. 1984. SELF-REGULATING FEEDING APPARATUS.

This description of valve answers when the boiler is low-pressure, or when the reservoir is more than 26 inches above the surface of the water for every pound of pressure per square inch of the boiler; for the height of the water in the cistern should be sufficient to balance the strength of the steam, and if this height be too small, the water in the boiler will be forced up the feed-pipe, and driven by the steam out of the valve. Water at a temperature of 60°, 2·94 feet in height, is equivalent to one pound on the circular inch, but the water in the feed-pipe is about 212°, so that 3 feet is required in height for every pound on the circular inch: it is necessary that the stone float should be placed in that part of the boiler where the steam will least affect it, and the feed-pipe should be as far away as possible from where the greatest quantity of steam is produced.

In High-Pressure Engines, the water is supplied to the boiler by a forcing-pump, worked by a lever connected with one of the reciprocating portions of the engine, and the water supplied by a pipe that traverses the steam which escapes, so as to become raised in temperature before it is admitted to the boiler: in order to proportion accurately the quantity of water to be supplied, we must remember that there is exactly one cubic inch of water for each cubic foot of atmospheric steam given to the engine, or one cubic foot equal to six gallons per horse-power per hour: but as the evaporation does not proceed uniformly, in consequence of variation in the intensity of the fire, which causes steam of greater or less density to pass into the engine, the steam sometimes falling below the standard and at others escaping through the valve, it is necessary to have some further means of regulating its supply. In some engines this is effected by a float; a stop-cock attached to the pipe of the feed pump will enable the attendant to regulate the

supply: this may be effectually done by having between the feed pump and the boiler a loaded escape-valve V, its load W being so adjusted that whenever the stopcock R is turned to impede the passage of the water towards the boiler, the force of the feed-pump pushes against the loaded valve at V, and by it passes through the return pipe into the reservoir of supply; this adjustment requires the attention of an attendant.

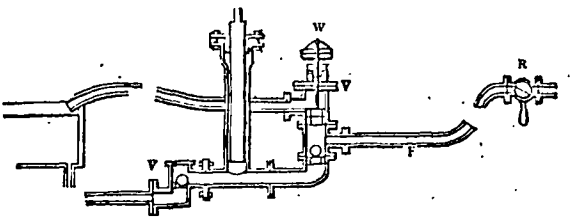


Fig. 1985. PIPE OF FEED-PUMP.

Safety-valves are of the utmost importance, and the greatest care should be bestowed on their construction; the earliest consisted simply of a weight laid on a hole in the top of the boiler: but this plan cannot be adopted when the pressure is high and the weight great, because it becomes unsteady: a valve is therefore used, as in fig. 1989., carefully ground to its seat; a spindle rising upwards carries a series of weights which may be increased or diminished; this being attended with inconvenience, a valve with an internal weight (fig. 1990.) has been contrived: but in all these modifications, when the pressure is high the weight becomes cumbrous. The lever safety-valve was introduced to

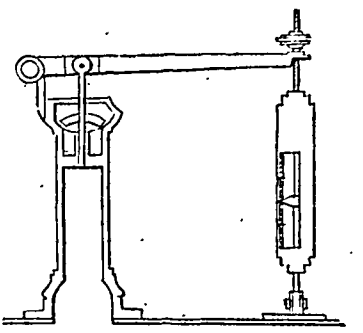


Fig. 1986. SAFETY-VALVE.

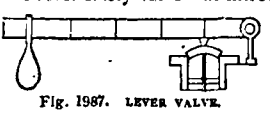


Fig. 1987. LEVER VALVE.

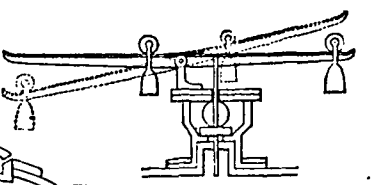


Fig. 1988. FRENCH SAFETY VALVE.

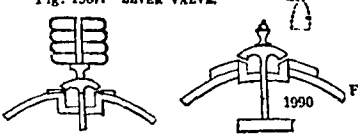


Fig. 1989. COMMON SAFETY-VALVE.

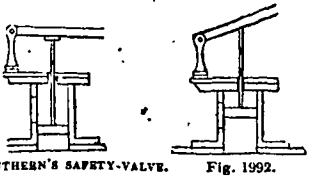


Fig. 1991. SOUTHERN'S SAFETY-VALVE. Fig. 1992.

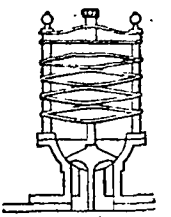


Fig. 1993. SPRING VALVE.

obviate this (fig. 1987.); a single weight hung on the longer arm of a lever produces an effect proportional to its distance, and the lever being graduated shows the amount of this effect. The form of fig. 1988. indicates still more correctly the point at which the pressure of the steam becomes equal to that on the valve which is flat or cylindrical, and acted on by a lever having equal arms with weights on each; these rest on light rollers, so as to run down from their places and release the steam entirely when the pressure reaches the prescribed limit. Figs. 1991. and 1992. show the form used by Mr. Southern in his experiments on high-pressure steam, the first when closed, the second when open. Fig. 1993. is formed of a series of bent springs placed alternately in opposite directions. Fig. 1986. is similar in principle, but has a lever interposed between the valve and the spring; both are employed in locomotives. Fig. 1994. was proposed by Mr. Nimmo for steamboat boilers.

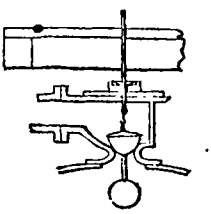


Fig. 1994. NIMMO'S VALVE.

The most certain and safe method for low-pressure boilers is to balance the pressure of the steam by a column of water, of a diameter sufficient to allow its escape: the height of the tube for different measures may be found readily, by considering that a column of water equivalent to one pound on a circular inch is for common temperature 3·1 feet; for pressure of 4 pounds on the circular inch it will be four times this, or 12·4 feet, which will be equal to a little more than 5 pounds per square inch: for high-pressure boilers the most careful attention to security is necessary, and serious accidents have occurred for the want of it, and it is obvious that the aperture by which the steam is to escape ought to be of a size that it may freely have vent, as fast as it is generated in the boiler: as $1\frac{1}{4}$ feet of fire-surface is sufficient to convert a cubic foot of water into steam, it is necessary for the purposes of security to calculate upon only 1 foot of surface being sufficient. If the *density* of the steam corresponding to the pressure be found, multiplied by 7·5, and this product again multiplied by the square root of the quantity, if the density is greater than 1, and the feet of fire-surface divided by the product; the quotient will be the square of the diameter of the movement part of the valve in inches.

Fusible metal plugs have been used as the means of forming safety-vents to steam boilers, which, by melting at certain temperatures, suffer the steam to escape, and alloys which melt from 212° to 600° of heat have been applied, but this kind of plug cannot be relied upon in practice.

Chimneys, and their Area for Steam-engine Boilers, form our next consideration. The fire-grate should have one superficial foot area for each horse-power; one-fifth of the area of the fire-grate gradually diminishing to a chimney, which shall have one-tenth the area of the fire-grate, is admitted to be an excellent proportion: the chimney should be of one diameter throughout its height, and if 40 feet, and its area one-tenth that of the fire-grate, its draught will be sufficient; when the height of the chimney exceeds this, the area may be diminished as the square root of the height is increased. For a low-pressure engine the area of the chimney, when above 10 horse-power, should be 112 times the horse-power, divided by the square root of the height of the chimney: when less than 10 horse-power its dimensions may be made less in proportion.

When engines are worked in the best manner, they require only 9 to 11 pounds of the best coal per hour for each horse-power, when the power of the engine exceeds ten horse. The flue must be proportionably increased when the smoke is the result of a consumption of a greater quantity of coal; when wood is used, there is a larger quantity of smoke, but as it is much lighter than that produced by coal, about one and half times the area necessary for coals will be ample. When circular chimneys are used, they should not be larger than is necessary to give effect to the fuel; this will be obtained when the square of the diameter is equal to 90, multiplied by the horse-power, and divided by the square root of the height in feet.

Piston Rods, their Strength. — The height of a column of water at a temperature of 60°, which presses with the force of one pound upon a square inch, is 2·31 feet, and upon a circular inch 2·94 feet; and in calculating the strength of the various parts of an engine, it is not only necessary to bear this in mind, but also the power of the steam in the boiler, and it will be perhaps safer always to take in our calculation double the pressure on the valve, for it is not always in the same degree of action: when the load on the valve is 8 pounds on the circular inch, call it double, and add this to the pressure of the atmosphere, which is 11·5 pounds; we then have 27·5 pounds for the strength of the steam acting on the circular inch: in steam-boats 39 pounds pressure per circular inch on the piston may be allowed.

The stress which acts on any portion of an engine may be ascertained by considering it inversely as the number of revolutions multiplied by the diameter of the circle, or the chord of the arc described by the point where the force acts; thus a wheel 4 feet in diameter, making three revolutions while the piston makes one stroke of 5 feet in length, will give $4 \times 3 : 5 ::$ pressure on the piston: the stress on the teeth of the wheel equal to that of the pressure on the piston. The cohesive force being known, the strain the material will bear is taken at about one-third.

Suppose D the diameter in inches of the piston, L the length of the stroke in feet, P the double of the whole elastic force in pounds upon the circular inch; l the length from the centre of motion to the centre of stress in feet; d equal to the depth or diameter, and b equal the breadth in inches; f equal the cohesive force of a square inch at the point of alteration; and R equal to the radius of the wheel. The force on the piston is then $D^2 P$ in pounds, or to find the diameter of the piston-rod in inches, multiply the diameter of the steam-piston in inches by the square root of twice the elastic force of the steam in the boiler in pounds per circular inch, and divide the product by 84. This rule applies when the strain on the rods is tensile, but when they are alternately compressed as well as extended, the diameter of the piston in inches should be multiplied by the square root of twice the pressure of the steam on a circular inch, and the product divided by 45, which

will give the diameter in inches for a piston-rod of wrought-iron: when cast-iron is used, divide by 42, and when steel, divide by 72 for the result instead of 45: when rods of air-pumps are to be considered, the pressure of the atmosphere and the diameter of the pump must be taken instead of the force of the steam and the diameter of the cylinder.

Beams, their Strength. — When of a uniform thickness it is not safe in cast-iron to make it less than $\frac{1}{6}$ of its depth, when the velocity is the same as that of the piston: $D^2 P l = 215 b d^2$; and when $16b$ equals d, and $12l$ equals n D, it becomes

$$D \left(\frac{1{\cdot}34 P n}{212}\right)^{\frac{1}{3}} = d;$$

D represents the diameter of the piston in inches; d the depth of the beam in inches, and the breadth $\frac{1}{6}$ of that depth; n, the number of times the diameter is contained in the length, from the point where the force is applied to the centre of motion; P, double the force of the steam in the boiler, in pounds per circular inch: half the depth at the centre of motion should be given to the depth at the end, keeping a uniform breadth: when wrought-iron is employed, substitute 240 for 212, and for wood 64.

Cranks, their Strength. — They should embrace the shaft, so that their depth should be $1\frac{1}{4}$ times the diameter of the shaft; thus, if S D be the diameter of the shaft, the depth of the crank will be 1·5 S D; hence $D^2 P L = 212 b d^2$; we have

$$\frac{P l}{2{\cdot}25\, S^2 \times 212} = \frac{P l}{477\, S^2} = b.$$

Cylinders and Metal Pipes, their Strength. — To determine the thickness of a cast-iron cylinder, the metal of which at an equal temperature is to bear a given stress; multiply 2·54 times the internal diameter of the cylinder by the greatest force of the steam on a circular inch, divide by the tensile force the metal will bear without alteration, and you have in the result its thickness in inches. The cylinder is supposed to have equal resistance throughout its length, and the stress upon an inch of that length is equal to the diameter in inches multiplied by the greatest possible force on a square inch, and the resistance as twice the thickness of the cylinder, by one-fourth of the tensile strain of the metal, the tension being unequal on the resisting part: thus, for a cast-iron cylinder of 60 inches internal diameter, for a pressure not exceeding 3·2 pounds per circular inch, in addition to the atmospheric pressure; to determine its thickness

$$\frac{2{\cdot}54 \times 60 \times 30}{15000} = 0{\cdot}305 \text{ inches:}$$

twice the force is here taken, or 30 pounds on the circular inch, and the resistance of cast-iron at 15,000 pounds the square inch. To determine the thickness of a working cylinder, where wear and other causes of pressure exist, multiply four times the elastic force of the steam in pounds per circular inch by the diameter in inches, and divide by 6000; this result, multiplied by the quotient arising from dividing the diameter by the diameter less 2·2, is the thickness for strength, to which $\frac{1}{4}$ inch may be added for wear.

Pistons, their Construction. — It is most important that they should not admit of any leakage, and Mr. Watt found that mutton tallow was the best adapted to keep the piston tight; when cylinders were new and imperfectly bored, the grease soon was wanting and the piston left dry; he afterwards mixed blacklead dust, but it was found that this application wore away the cylinder, but they are now made so true as not to require it, or at least only for a short time. Pistons are usually of metal, and are formed so as to have some elasticity: the common piston is a double cone of wood having secured around it by strong nails a couple of bands of leather; when of metal, they are usually turned out of brass, and made to fit the cylinder in which they are to move, so that without much resistance they will slide to and fro; on this as well as below is a plate, between which and the cylinder of brass is inserted two leathers cupped, with the edges chamfered off to an angle of 45°.

The piston for the atmospheric engine is a plate of cast-iron, about $\frac{1}{4}$ inch less in diameter than the cylinder, and $1\frac{1}{4}$ inch in thickness, with a rim about 4 inches from the edge; beyond this a flat ring is fitted, and they are screwed together, after hemp mixed with tallow has been inserted between them to form the packing.

The hemp-packed Piston is that in general use: the bottom is accurately fitted to the cylinder, and the upper part is cut away to admit of gasket or unspun hemp or soft rope being wound evenly round it, which forms the packing; this is compressed by a plate by means of the screws: the piston-rod is usually attached to the bottom of the piston, and it is secured by a screw-nut inserted between the top and bottom; melted tallow is applied by a funnel on the top of the cylinder lid to the piston.

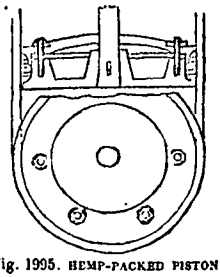


Fig. 1995. HEMP-PACKED PISTON.

The Wedge Metallic Piston is formed of rings cut into a number of parts, pressed upon the cylinder by wedges, which again are kept in their places by springs, and thus a more perfect adaptation of the ring to the cylinder is supposed to be obtained.

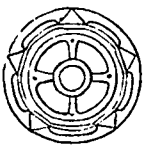


Fig. 1996. WEDGE METALLIC PISTON.

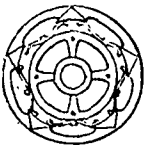


Fig. 1997.

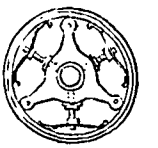


Fig. 1998. SPRING METALLIC PISTONS.

In the Spring Metallic Piston, fig. 1997. wedges are inserted behind the rings, with springs behind them, forcing them outwards, and in fig. 1996. a single elastic hoop is substituted for all these springs: springs without wedges are also in very common use for metallic pistons with divided rings, double sets being used and the springs pressing directly on the segments of the metallic rings, as in fig. 1998.

Wolf's Piston is so contrived as to enable the engine-man to tighten it without taking the cover off the cylinder; the piston-rod forms part of a screw to which a toothed-wheel is attached; this is turned by means of a pinion provided with a square head rising in a recess in the cylinder surmounted by a cap.

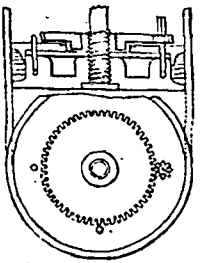


Fig. 1999. WOLF'S PISTON.

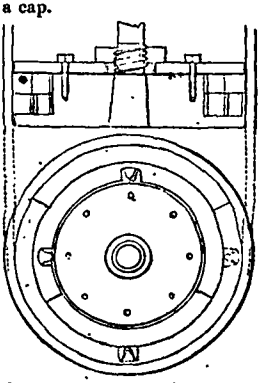


Fig. 2000. CARTWRIGHT'S PISTON.

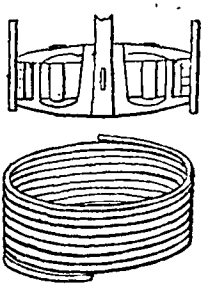


Fig. 2001. JESSOP'S PISTON.

Cartwright's Piston is very similar to the wedge metallic piston, but has not been found quite successful in practice, when the cylinders are not truly bored; the pieces forming the piston having a determined curvature, and being too strong to be sensibly flexible, cannot accommodate themselves to any irregularity, as is done by the elastic stuffing of hemp.

Jessop's Piston consists of an expanding coil of metal which binds round the piston body in a spiral form, fig. 2001.: a bed of hemp packing is first prepared, which answers the double purpose of preventing steam passing at the joints, and of supplying a means of pressing the springs against the surface of the cylinder; their pressure and wear is more equable than in other metallic pistons, and they have been successful in practice.

When a piston-rod is drawn as well as pushed, the proportion of its diameter to that of the piston should be attended to, as the slightest inequality in the centering, or in the friction will render it liable to stick and not move properly: in high-pressure engines the friction and loss are estimated at two-tenths of the power. The piston-rod, collar, or stuffing-box, is that which admits the smooth rod or plunger to pass into the cylinder or air-tight vessel; the stuffing-box with the hemp packing surrounds the piston-rod; round it is a collar, with a hole sufficient to allow the rod to pass, which is stuffed and screwed down with similar stuffing to that already described.

The common Clack-valve is a piece of leather rather larger than the opening it is to close, and is attached by a joint or hinge; it is strengthened by a metal plate on each side, the lower one less and the upper larger than the aperture: an angle of 30° for it to open allows a free passage.

A double Clack-valve is used for pump-buckets; they should also rise to an angle of 30°, and are decidedly preferable for large pistons.

Conical Steam-Valve is a metallic plate with bevelled edges, made exactly to fit into a conical box, and is sometimes called a T valve; the valves of Watt's engine were of this kind. The diameter of the box should be to that of the greater diameter of the valve as 3 to 2, and should rise at least one-fourth of its greatest diameter when open; they are usually of brass, and are turned so as to exactly fit, after which they are further ground into each other with emery powder; the angle is 45°. When this valve is to be self-acting, its weight must be equal to the square of the diameter multiplied

by the pressure in pounds on a circular inch; it will then move as soon as its narrower surface is exposed to a given pressure.

The Cup Valve is made with the seat a portion of a sphere, and the valve itself a sphere or portion of it to fit it: they are occasionally used as safety-valves; a weight is suspended below them to prevent sticking.

Sliding Valves are in general use, and consist of a box with a slider at right angles to the passage, moved by a rod passing through a stuffing-box. The slider is accurately ground, and is held by a spring; for small apertures it is moved by a handle, and for larger ones by a rack and pinion.

Crown or Equilibrium Valve used in the Cornish engines, and also in the rotative: it requires little force to work it. The steam is introduced through the pipe S, and the aperture A is surrounded by an upright ring or collar, rising a few inches into the chamber, which ring is perforated by slits of considerable size, but closed at the top. The crown or cover of the valve is a ring attached to a steel rod, by which it is raised or depressed, care being taken that the collar and crown valve are both accurately ground and made to fit each other.

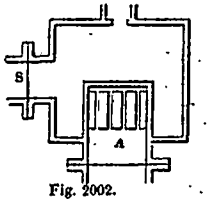


Fig. 2002. Fig. 2003.

CROWN OR EQUILIBRIUM VALVE.

When the valve is on its seat, it is closed on all sides, so that no steam can enter: when raised up from its seat, the steam may enter freely from each of its sides: this kind of valve is similarly arranged to the conical valves, and work in the same way, four of them being used in a single engine. The conical valve was contrived by Mr. Watt, and is shown when open in one figure, and shut in the other.

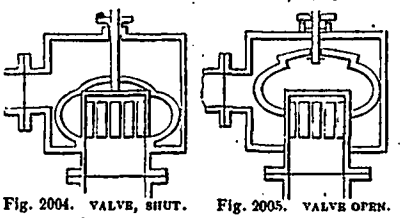


Fig. 2004. VALVE, SHUT. Fig. 2005. VALVE OPEN.

S is the entrance for the steam, A the port, V the conical valve, N the seat or nozzle, which it covers: when the conical cover V of the aperture N is up, the steam has free admission; when it is closed, the steam presses the valve down into its seat, without escaping from the nozzle.

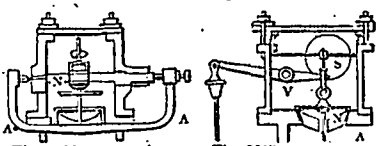


Fig. 2006. WATT'S CONICAL VALVE, OPEN. Fig. 2007. DITTO, SHUT.

Murray's Sliding Valve.—All the apertures terminate in a case that is steam-tight, and within which a box slides up and down, which opens and closes the passages alternately. The rod O, which passes through a stuffing-box, moves the sliding part. The steam entering from the boiler at S passes through *a* to the top of the cylinder when the slide is down, while the passage to the condenser is open through the interior of the slide; when the slider is up, the passage *b* from the bottom of the cylinder is open, and the passage *a* from the top to *c*, the condenser, is open: to drive this slide a small reciprocating motion is sufficient, and it has considerable friction from the pressure of the steam against the box; they are generally of gun metal where salt-water is used, and they act and wear well.

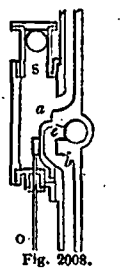


Fig. 2008. MURRAY'S SLIDE.

Rotary Valves are formed by a plate of metal moving on an axis, which crosses the plate, and passes through an air-tight aperture to the outside: for throttle-valves, or where perfect tightness is not the object, they may be usefully employed.

Four-way Cock is used to open a communication alternately from the boiler and condenser to the top and bottom of the cylinder: it is simple in its action, but steam is lost at each stroke of the engine, and there is considerable friction; it is of a cylindrical form, and when truly ground the steam tends to keep it tight, but it soon wears into an elliptical shape and requires re-grinding. In a four-passaged cock made for the purpose of shutting off the steam at any period of the stroke, without closing the passage to the condenser, T shows the passage to the top, B that to the bottom of the cylinder, and C that to the condenser; the figures show its position when the steam enters, and when shut off.

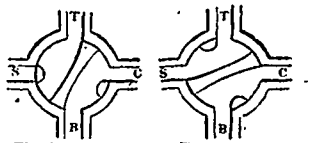


Fig. 2009. SHUT. Fig. 2010. OPEN.

FOUR-WAY COCK.

To form the four-way cock, so that the steam can be cut off at any portion of the stroke, it must be enlarged sufficiently to allow the breadth of two apertures between the middle

and each adjoining passage, increasing the diameter in the proportion of 10 to 8, the rubbing surfaces remaining nearly the same, and the cone will be more equally pressed into the socket. The most simple method in practice is to make use of two double-passaged cocks.

Plug Tree is a rod attached to the engine beam, and provided with *tappets* or projecting pieces which strike levers or handles of valves for the purpose of shutting or opening them at various intervals, as the rod descends or ascends. The handles turning on their axis act as levers, and thus move the cocks, slides, or valves, to which they are attached.

Valves opened by Weights. — Fig. 2013. W is the weight, which acts upon an arm *a* on the axis, and requires to be turned, that the valve may be moved: a spring-catch *b*, held by the suspended weight, closes the valve, which opens when the catch is disengaged, and the handle c is moved by the tappet *d*: direct action from the beam itself is now used to open these valves, and the weights are in great measure dispensed with, though they are said to open the valves more rapidly, which is important for working the engine, as the opening and closing the passages at the proper time constitute its effect.

A weight opening a valve may descend into a vessel of water, while the aperture by which the water escapes from under it may be increased or diminished at pleasure. The weight uses its full force to open the valve, but when it begins to move, it is stopped by the water: in the ascent, a valve at the bottom of the vessel opens inwardly, and the engine has only to raise the weight again. This method is in constant use for opening valves of engines for the purpose of raising water.

Eccentric Rollers, to raise the valve-rods, are ingenious, though attended with some objections in their application. Fig. 2012. shows a section of the steam pipes and valves of Fenton and Murray's double engine, and fig. 2011. the communicating rods: by the pipe C the steam enters: at *a* is a throttle-valve, which regulates its supply: a governor of two

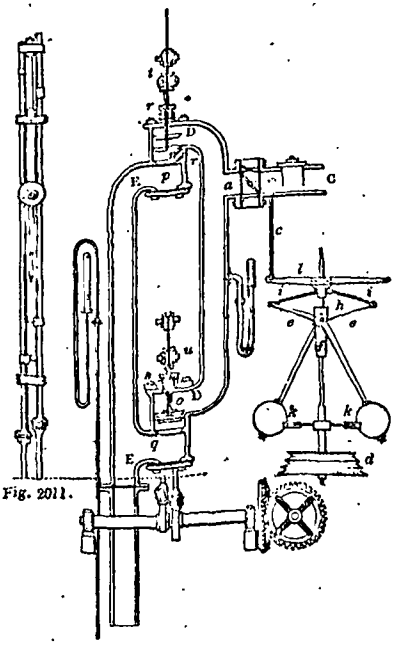


Fig. 2011.

Fig. 2012. FENTON'S STEAM-PIPE AND VALVE.

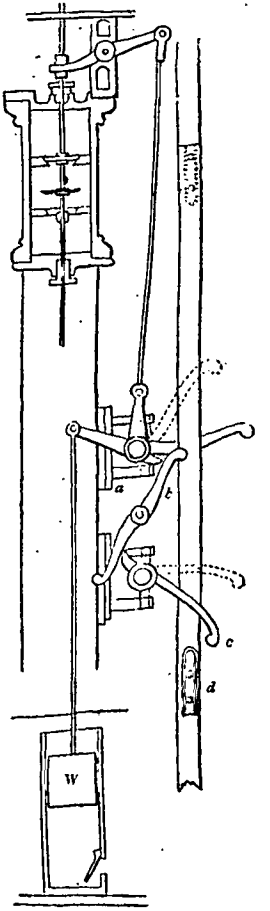


Fig. 2013. OPENING-VALVES.

bent levers *e*, *e*, turning upon its axis at *f*, has a rotary motion communicated to it by means of a band passing from a pulley to a similar pulley at *d*. The upper part of the spindle has a slide *n*, which is connected by rods *i*, *i*, to the levers, which rises when the centrifugal force of the governor is increased, and descends when it decreases; as the lever *l* is affected by the rising or falling of the balls of the governor, so is the valve *a* attached to it.

The arms *k, k*, serve as rests to the balls when the engine is not at work, and the rod *c* is raised to such a height that the throttle-valve is in a horizontal position, and the passage of the pipe open for the admission of steam: by the pipe D D the steam passes either to the top or bottom of the cylinder through the throttle-valve *a*, and then down to the condenser, through the pipes E, E: the valves *n, o*, have each a spindle passing through the stuffing-boxes *r, s*. The rods of the valves *p* and *q* have also at *t* and *u* stuffing-boxes to pass through, which rods open the eduction pipe E; thus the valves for the admission or eduction of the steam are opened without any escape. The sliding rods, which give motion to these valves, are kept in a perpendicular position by bands.

Modes of opening Valves, Cocks, and Slides, or the means by which the engine is rendered automatic, or capable of performing its work without the assistance of manual attention to open and shut them, is a matter of the greatest importance, and has partly been described; but one of the most perfect is that of deriving the motion of the valves from a connecting

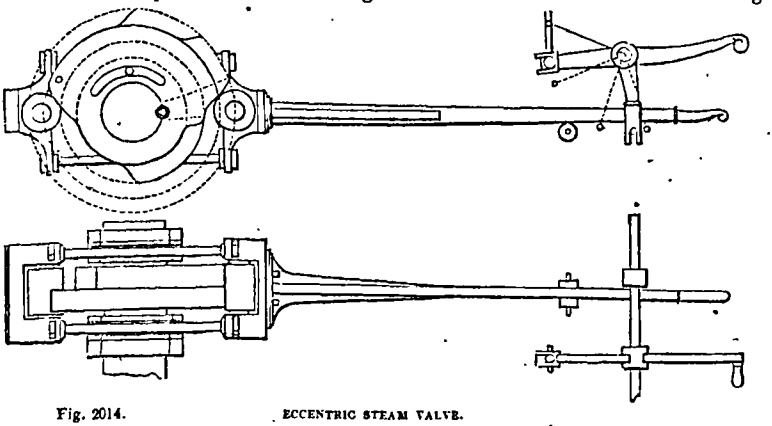


Fig. 2014. ECCENTRIC STEAM VALVE.

rod, one end of which is made to move round in the circle of a crank, while the other end performs a rectilineal or circular reciprocating motion: another method is by

The Eccentric, which is a circular disc or ring of metal, placed upon the shaft or axis, turned by a crank. The distance from the centre of the disc to the centre of the axis is called the eccentricity, and is equal to half the throw or range of the motion of the valves to be moved by it; the rod is called the eccentric rod, and is attached to a hoop that exactly fits the disc: this produces an easy change of motion, and being constantly moving gives no stroke at the time of change. Suppose *r* to be the radius of the eccentric circle, and *d* the distance of its centre; from the centre of motion then $r+d-(r-d)$ will be the extent of the movement, $=2d$, or twice the eccentricity. At $\frac{1}{8}$ of the stroke, counted from either end, a valve can only be opened half way; at $\frac{1}{8}$ part of the stroke it may be calculated to be fully open: sometimes the valve rods are made to branch out into four portions, and at their separation a flat brass plate is inserted, with another at the summit to unite them: the eccentric works between the side forks of the rod, and bears against its top and bottom plates, figs. 2015. 2017.: the other forks are in width equal to the diameter of the axle, which prevents the rod deviating from the vertical position, figs. 2016. 2018.; by adding a handle that can be worked by hand, the reversing process may be performed.

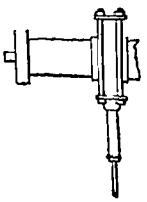


Fig. 2015.

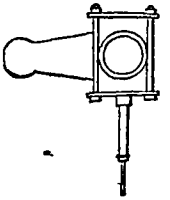


Fig. 2016.

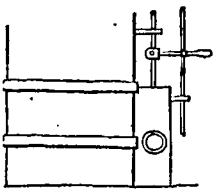


Fig. 2017. PLAN.

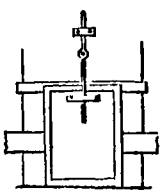


Fig. 2018.

The Governor, or *Centrifugal Power Regulator*, is an ingenious contrivance for equalising motion, in the steam-engine particularly; by its means the valves which suffer the steam to pass from the boiler to the cylinder are opened or closed to the extent necessary, and in such a manner as to allow a certain quantity of steam to pass through, and no

more. When the action of the governor flags, the valves open more, and *vice versâ*, so that it produces a motion free from vibration: this is effected by suspending two or more balls from a revolving axis, and allowing them to revolve with it: when the velocity is increased the balls rise, and when it is diminished they fall: by connecting arms to the rods by which the balls are suspended, their rising or falling moves a lever, which can be applied either to open or close a valve. The vertical distance between the point of suspension and the plane on which the centre of the balls revolve corresponds with the length of a pendulum, which makes one vibration, forward and back again, in the time the balls make one revolution. The common velocity given to the axis is about thirty revolutions in a second; consequently the height should be equal to the length of the seconds' pendulum, which is 39·14 inches: to find the height for any other number of revolutions, divide 35·226 by the square of the number, and the quotient will be the height required. The balls usually weigh from 30 to 80 pounds, and the angle the rods make with the axis is about 30° when they are at rest: the motion of the governor is derived from the engine, by a cord or strap running round the axis of the fly-wheel and, communicating its motion to a pulley which is fixed upon the spindle or upright rod: when the axis of the fly-wheel moves too rapidly, its increased motion is communicated to the governor; its spindle then revolves more rapidly, and the balls attached to it, from their increased centrifugal force, fly out farther from the spindle, and depress the levers which act upon the throttle-valve so as to contract it.

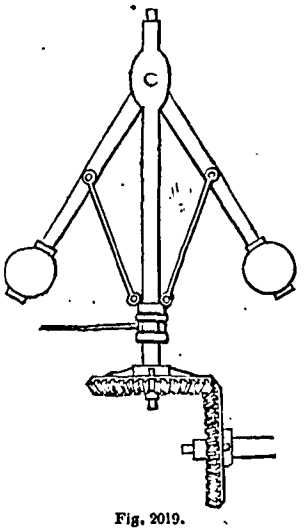


Fig. 2019.

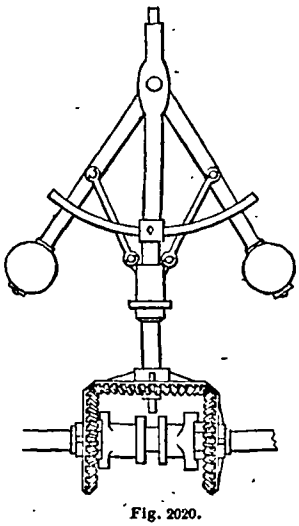


Fig. 2020.

Parallel Motion was the means of establishing a communication between the inflexible rod of the piston, which oscillates in a straight line, and the beam which oscillates circularly; this elegant arrangement is not perfect, and some allowance is requisite to be made in the adoption of it upon a large scale, to prevent serious inconveniences to the machinery to which it may be applied: three angles of a parallelogram describe arcs of a circle, while a fourth, which lowers and raises the piston-rod, moves nearly in a straight line; this will be shown by supposing R the top of the piston, and B the head of the beam, which describes the segment of a circle whilst R moves in a vertical direction; these motions are made to suit each other, by having a fixed point at F, which is placed close to the line, in which the piston-rod moves: on the beam, at B and E, are hung the inflexible bars B R and E H, which move freely on their pivots: the other extremities of these rods are connected at R H; another rod passes from H to F: these several rods have free motion around their pivots. The head of the piston being attached at R, the piston-rod will then have a vertical motion; from the outward motion of the beam, during the first half of its descent and the first half of its ascent, or from its inward motion, during the latter half of its descent and the latter half of its ascent. When the beam is in an horizontal position, as is shown by the dotted line *c k*, the rod B R will hang in a perpendicular direction, and

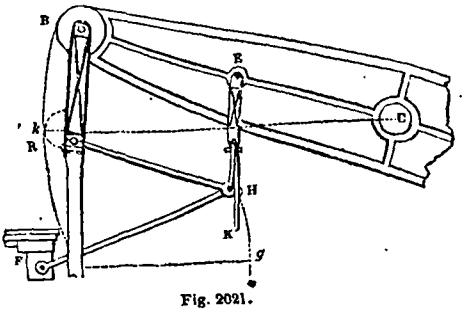


Fig. 2021.

that of F H will be horizontal, as shown by the line F g' during the latter part of its descent the point B will be bent inwards, and press with it the head R of the piston-rod; the rod F H will then bend outwards, and thus resist the inward thrust of the beam; in the ascent similar adjustments take place between the beam and the piston-rod, the latter being always preserved in a vertical position, or nearly so, and the strain it is subjected to in one direction neutralised by the opposite action of the rod R H. This motion may be further understood by supposing it to be required that the top of the piston-rod P, fig. 2022., should not be moved by the obliquity of its connecting rod P R, which may be prevented in this manner: at s, s, are two fixed points, at equal distances from the piston-rod; there are two parallel bars g, g, placed between the piston-rod and these points, which steady the motion, and revolve freely on their points s, the ends of the bars g, g describing arcs of circles; these rods being attached to the piston-rod in the middle of the two points g, g would have the effect of always keeping the point P in a straight line; thus the piston-rod is not attached to the ends of the guide bars, but to the middle of the link; the point P therefore is prevented from deviating much from the straight line.

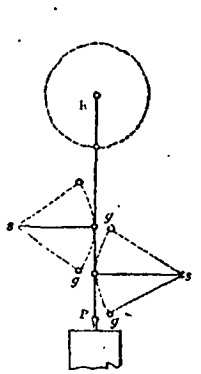


Fig. 2022.

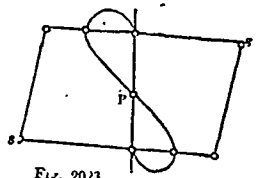


Fig. 2023.

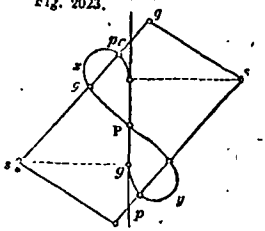


Fig. 2024.

The point P does, however, deviate from a straight line, and forms a double curve; and in practice it is necessary to make some allowances for this, which may readily be shown by tracing the point p during its motion: when $g s$, fig. 2024. comes into the straight line with the link $g g$, the point p deviates from the straight line, by a quantity equal to p', and this is reversed in the opposite extreme. When the link $g g$, fig. 2023. comes into the same line with the bar $g s$, the deviation is much greater, and when the links have returned to their original position, they have described the whole curve $x p y$. This deviation increases more rapidly than the square of the length of the stroke; the greatest deviation at the end of the stroke being ascertained, and also its amount, at one-eighth part of the stroke from the middle, bring the centres s, s each nearer to the other, by a quantity equal to the deviation at the eighth part, and the amount of its greatest deviation will be reduced to less than one quarter of what it was in the first instance: the parallel motion of one point may also be readily transferred to another by jointed parallelograms.

Fig. 2025. shows the simplest kind of parallel motion, and is usually employed to communicate the rectilinear movement to the air-pump-rod of the steam engine. Fig. 2026. is the apparently more complicated case in which three shorter bars are added to the end of the beam, so as to form a parallelogram, to the lower angle of which the piston-rod is attached. Fig. 2027. exhibits the parallel motion used for steam-boat engines: the beam A F is below the cylinder; when A B is equal to D C, the point E is in the middle of the length of the bar B D: the rod D G may be at any height, provided it be parallel to A F, and B may be at any point in A F. Fig. 2028. shows how to arrange three piston-rods to move parallel: as for Wolf's engine, the points of suspension must be all in the line A G. Fig. 2029. shows another arrangement for three rods at one end and two at the other end of the beam: when the proportions to obtain parallel motion have been found by the following rules, the point for the air-pump-rod in the link D B is easily found by drawing a line from G to A, and then the rod must be attached to the point of intersection. In like manner, in any complex case, as in Wolf's engine with two cylinders, the points of connection for the piston-rods must all be in the line A G. In these figures the corresponding parts are marked by the same letters.

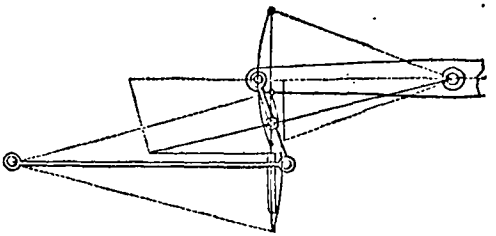


Fig. 2026. PARALLEL MOTION.

To find the length which should be given to the radius bar, when the length of the beam from the centre of motion is to half the length of the stroke as 3 is to 2: from three times half the length of the stroke, subtract twice the length of the parallel bar, and

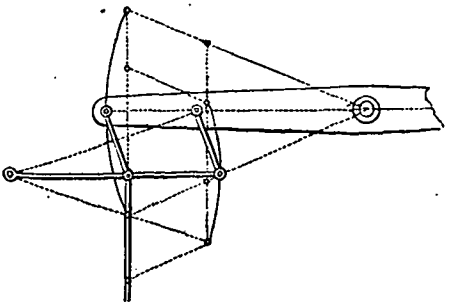


Fig. 2026. PARALLEL MOTION.

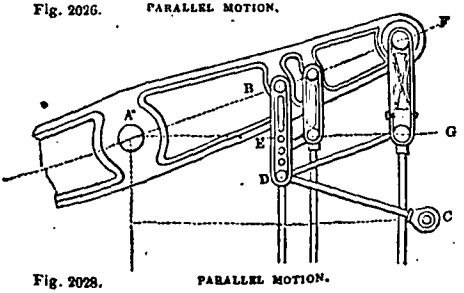


Fig. 2028. PARALLEL MOTION.

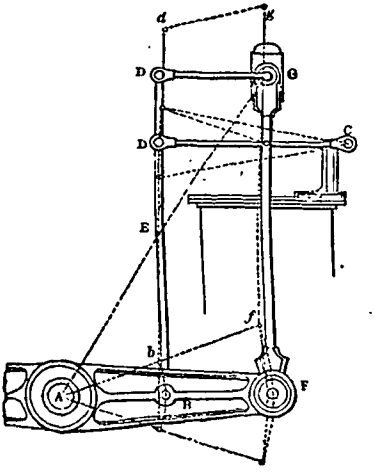


Fig. 2027. PARALLEL MOTION FOR BOATS.

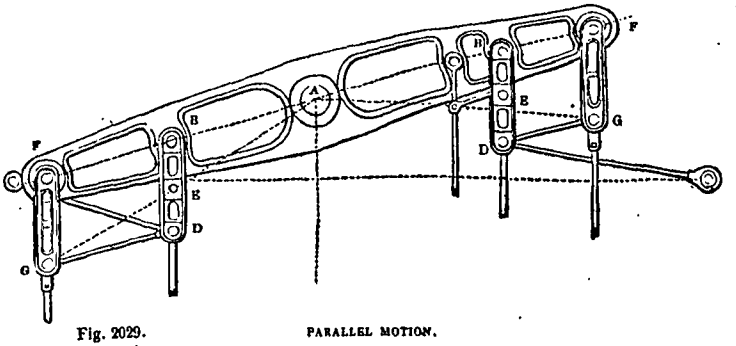


Fig. 2029. PARALLEL MOTION.

multiply the difference by half the length of the stroke; this product divided by ·343146 times the length of the parallel bar, and the quotient added to the length of the parallel bar, gives the length of the radius bar. The radius bar and the parallel bar should be of equal length, when twice the parallel bar is equal to three times half the length of the stroke.

When there is no assigned proportion between the length of the stroke and the radius of the beam, the length of the radius bar is thus found: first, from the length of the radius of the beam, subtract twice the length of the parallel bar, and multiply the difference by the square of half the length of the stroke; secondly, find the square root of the difference between the square of the length of the radius of the beam and the square of the half length of the stroke, and subtract this root from the length of the radius of the beam, and multiply the difference by twice the length of the parallel bar. This product becomes a divisor to the number found by the first part of the operation; the quotient obtained, added to the length of the parallel bar, gives the length of the radius bar.

Cartwright's Parallel Motion, (figs. 2030, 2031.) consists of two toothed wheels, which work in each other, and from corresponding points in their circumference two connecting links unite at the extremity of a cross bar, to the middle of which is joined the piston-

rod. These wheels and connecting rods being always in similar positions, on opposite sides of the piston-rods, the obliquity of their actions balances each other, and the rod is made to describe a straight line; to make this arrangement work accurately the greatest nicety of execution is necessary.

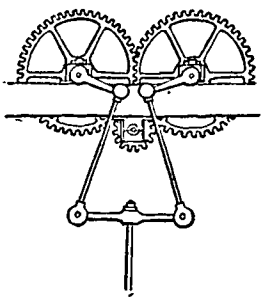


Fig. 2030. CARTWRIGHT'S PARALLEL MOTION.

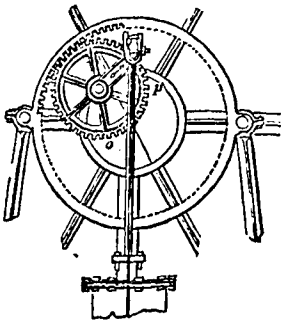


Fig. 2032. CYCLOIDAL MOTION.

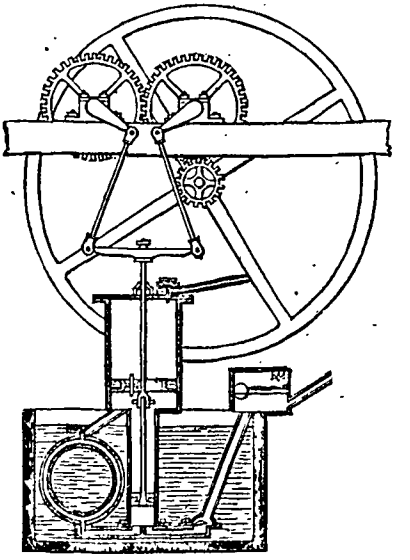


Fig. 2031. PARALLEL MOTION.

The Cycloidal Parallel Motion, which is exceedingly beautiful, depends on the principle that an encycloidal curve, described by one circle rolling within another, approaches a straight line, as the inner circle becomes more nearly equal in diameter to the radius of the outer one. The large wheel, which has teeth on its inner circumference, is fixed on a frame concentric with the axis and circle of the crank *o*: the small wheel, which has teeth on its outer edge, is freely fixed on the crank-pin, and *p* is the point at which the piston-rod is affixed. The small wheel is forced by the pressure of the piston-rod upwards, to roll round the great circle, ascending on the one side and descending on the other; so that the distance of the end of the piston-rod from the point of contact of the circles is always equal to the distance of the circle from the diameter.

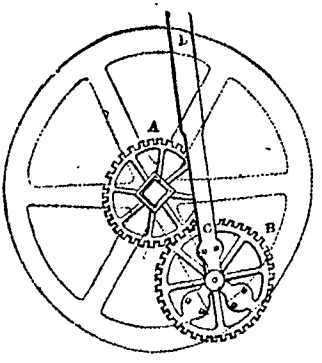


Fig. 2033. SUN AND PLANET WHEEL.

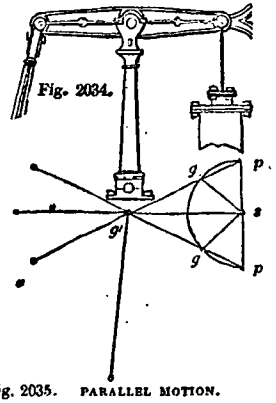


Fig. 2035. PARALLEL MOTION.

The Sun and Planet-Wheel, (fig. 2033.) was contrived by Watt: a toothed wheel A is fixed centrally with the large wheel to which the rotary motion is to be conveyed; B is another toothed wheel fixed firmly to the end of a vertical rod C; a strong link connects the centres of the two wheels. If the shaft D be turned, the wheel B will revolve in the same direction, and elevate the rod C till it arrives at the top of the wheel A, when, by continuing the motion of the large wheel, B must descend to its first position, and so on continually.

Another species of parallel motion has a joint at the bottom of the column, (fig. 2034.) on which it and the beam and the crank rod perform a joggling motion backwards and forwards during each stroke, which may be better understood by supposing the point *s* (fig. 2035.) on the plan fixed; *s*, *g* are movable bars. The point *g* describes a circle round *s*, so that *p* describes also a curve round the same point: the oscillation of the moving mass of the engine in alternate directions, with a sudden jerk at the end of the stroke, renders this kind of movement injurious to engines on a large scale, particularly as the piston-rod also deviates very considerably from a straight line.

Fig. 2036. shows another method of converting rectilinear to circular continuous motion employed in steam engines, with its accompanying geometrical demonstration. Let *aed* represent the fixed, and *ac*, *b'c* the interior revolving wheel in two positions, its first, being at the extremity of the diameter *ad*; when it comes into any other, *bc*, the point *a* will always be found in the diameter *ad*, since whatever be the position of the centres *o*, *o*, $ba = b'a'$

The Crank is one of the most important appendages of the steam-engine, and is used for converting a reciprocating into a rotary motion. By the force of steam, motion is produced upwards and downwards, in the right line of the axis of the cylinder, and this can be rendered capable of producing a force equally well in a circular direction: when an engine is used for pumping only, a crank is not necessary, but when applied to machinery, its use is highly important; it increases the velocity of the moving force, and in ordinary construction this is in the ratio of the circumference of a circle to twice its diameter.

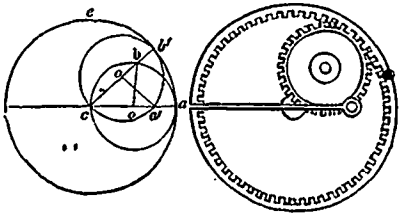


Fig. 2036. EPICYCLOIDAL MOTION.

The moving force of a crank may be uniform and in a straight line; or it may be uniform in a curved line, or it may be variable in either case: on examining the action of the crank, it will be found neither to be continuous in direction nor in action: when the steam enters below the piston, it forces it to the top of the cylinder; it is then cut off preparatory to its entering above the piston, and in the interval it has no action, and this is the case after the steam has forced the piston to the bottom of the cylinder: this double cessation of action between the impulses would prevent the continuous revolution, were it not for the addition of a wheel, by which means is obtained the power of continuing motion, by what is termed its momentum; such a wheel attached to an axle is called a fly, and serves greatly to equalise motion; it is usually of large dimensions, and its rim of considerable weight, in order that the action may be regular and uniform. The fly-wheel, although partial and not quite perfect in its equalisation of motion, so far improves the action of the crank, as to make it applicable to all ordinary purposes; the extreme delicacy which results from the motion of the water-wheel is, however, superior where great nicety of movement is required.

The motion of the crank may be shown by supposing E the extremity of the beam, moving in the arc of a circle, and C the rod or axis, to which a regular continuous circular motion is to be given: let a short bar D B proceed from the rod to be turned, and play upon the pivot B, to which is attached, playing also freely upon it, a long bar or rod E B, the other extremity of which turns in a pivot E, at the other end of the beam; the rod E B, descending as the beam descends, and moving up with it, will turn round the crank B D, the extremity B describing a circle C. There are, however, two points in the revolution which are called dead points; for when the end of the beam is at its greatest elevation, the rod hangs perpendicular, and the crank is in the same line; the beam then depresses the crank and axis, and will not turn either, and when the end of the beam is at its lowest point, the crank is also in a line with the rod. The motion of the crank, which it acquires before it reaches these two dead points, carries it beyond them, and the beam resumes its natural action, and this is further aided by

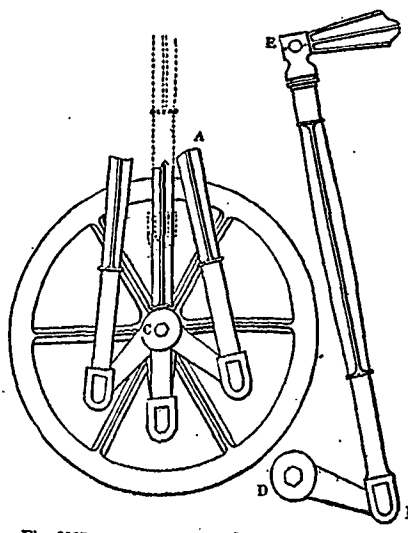


Fig. 2037. CRANK AND FLY-WHEEL.

the fly-wheel. The crank moves more slowly when at these points, and more rapidly in its other positions, from which there is inequality of motion in the axis.

The Fly-wheel is a necessary part of the machinery, where perfectly steady and uniform motion is the object: it consists of a large wheel with a heavy rim, usually formed of iron, is attached to the axis on which the crank turns, and revolves along with it; by its weight it acts as a drag on the engine, and prevents its motion being too rapid, and the impetus it acquires from its weight, it carries on the machinery with the usual or gradually decreasing force, when the proportion of the resistance to the power becomes augmented, and the engine has a tendency to move slowly; its heavy rim absorbs any surplus force which it acquires, and yields it again when required; it is a reservoir which collects the intermitting currents and sends forth a constant and regular stream.

To proportion the rim of the fly-wheel, multiply 40 times the pressure of the piston in pounds, by the radius of the crank in feet, and divide this product by the cube of the radius of the fly-wheel in feet, and by the number of its revolutions per minute; this result will give the area of the rim of the fly-wheel in inches; the number of the horse-power multiplied by 200 will be the greatest pressure on the piston. When the velocity of the fly-wheel exceeds 12 feet at the rim per second, its arms should be of wrought-iron, and a velocity of 33 feet per second at the rim is the extreme velocity that should be given at any time; with cast-iron rims, the velocity should not exceed 18 feet per second, that they may be perfectly safe. The proportions of the fly-wheel are derived from the laws of rotary motion, and are found by adding the time, the radius corresponding to the angular velocity of the exterior ring of the wheel; and comparing with the force of gravity to obtain the co-efficient; it is,

$$\frac{32\ \mathrm{P}.\ dr t}{b x^2} = n v.$$

P here is the mean quantity the moving force varies in its intensity in excess above the resistance, and t the time in which that variation takes place; v, the velocity, and nv, the greatest variation of velocity; d, the leverage the force P acts with; and r, the radius corresponding to the velocity v; and b, the weight of the fly, acting at the distance x from the axis: the weight of the rim being always at the extremity of the radius; $x = r$, and the equation becomes,

$$\frac{32\ \mathrm{P}.\ dt}{br} = nv.$$

When the weight of the rim is great, it acquires a great momentum with little increase of angular velocity, or it loses a considerable momentum with a small diminution of that velocity; and the greater the angular velocity of the axis of the fly is, the greater will be its equalising power, all other things being equal: variation of velocity is inversely as the velocity of the rim.

To measure the useful Effect of an Engine.—The most convenient method is by the means of friction: if the rim of a brake-wheel on the engine shaft of a given diameter, be pressed with a force exactly equal to the effect of the engine at its working speed, then the friction being ascertained, which this pressure produces, the power of the engine may be found by multiplying the friction by the velocity of the rubbing surface.

Let A B be a lever, tightened by a friction strap, which passes round the shaft or wheel C; the lever being stopped at the point D till the friction be equal to the power of the engine when all other work is thrown off; then, while the engine is in motion, place at E a weight sufficient to retain the lever in its horizontal position: to obtain the power, multiply the length F C in feet, by the weight placed at E in pounds, the number of revolutions per minute made by C, and 6·2832; the result will be the number of pounds raised in a minute one foot high, which divided by 33,000 gives the horse-power. Suppose l be the leverage the weight w acts with, r the radius of the wheel or shaft c, the friction f, the velocity o, the revolution of c per minute n; then fv equals the power, and $f = \frac{lw}{r}$, and $v = 6{\cdot}2832\, rn$; consequently, $vf = 6{\cdot}2832\, lwn$, the power in pounds raised one foot, when l is in feet and w in pounds.

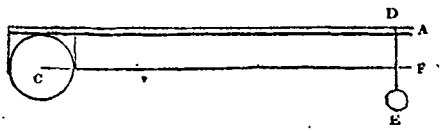
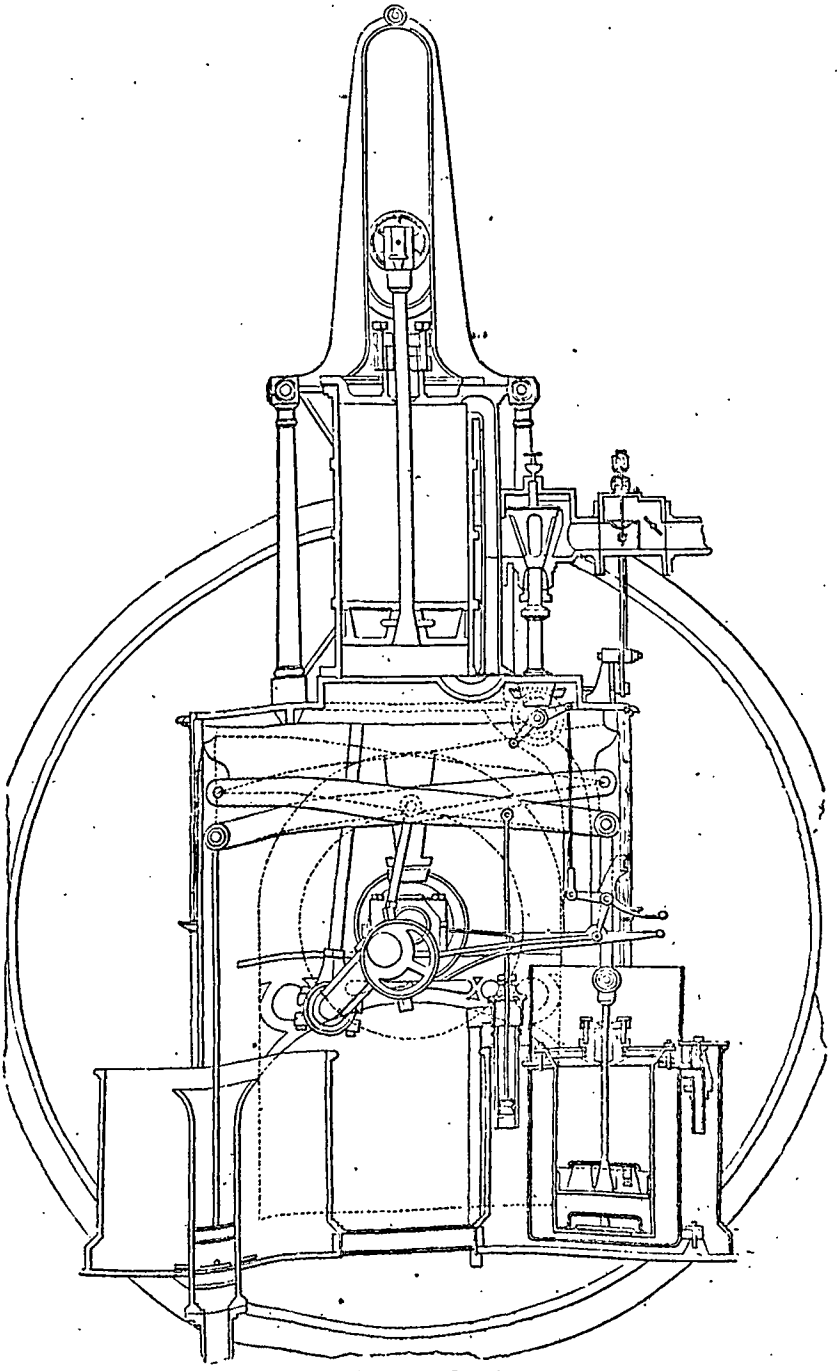


Fig. 2038.

The portable Condensing Engine.—The cylinder is supported by a cast-iron frame, and two eccentric wheels on the crank-shaft give motion to the levers by connecting rods: the lever works the cold-water pump by a rod, while the beam, by means of slings, works the air and hot-water pumps. On the cross rail is a guide to confine the air-pump rod to a vertical motion: the condenser surrounds the air-pump, and is again surrounded by

one of the cold water cisterns; the two cisterns are connected by a pipe: the steam from the cylinder passes by a pipe to the condenser, where the cold water is admitted by a cock:



PORTABLE CONDENSING ENGINE.

Fig. 2039.

the air and condensed steam ascend through a foot-valve into the air-pump. The opening and closing of the steam passages is performed by the eccentric, fixed on the crank shaft, the action of which communicates a reciprocal motion to the rod, which, by a bent lever, moves the connecting rod and lever fixed at one extremity of a spindle, having a bevelled wheel at the other, which works into another spindle of the steam-cock, admitting the steam into the cylinder: on the fly-wheel shaft is a pair of bevelled wheels, communicating motion to the governor balls, which keep the valve on the steam pipes open a longer or shorter time, according to the velocity of the engine.

Application of Steam Engines for raising Water. — By means of an engine acting expansively, 280,000 cube feet of water may be raised by one bushel of coals a foot in height, and when a pump is applied for this purpose, its stroke should not exceed 8 feet, and the diameter of its cylinder 14 inches: the velocity of the piston should not exceed 98 times the square root of the length of the stroke. The quantity of water in cube feet delivered at each stroke of the pump is $\cdot 00518 l d^2$ = the quantity in cube feet, l being the length of the stroke, and d the diameter of the pump in inches. The power required to raise water to a given height is found by taking the height in feet from the surface to the point of discharge, and adding a foot and a half for each lift, for the force required to give the water the velocity, and also add one-twentieth of the height for the friction of the piston, and call this quantity in feet h; then $\cdot 341 h d^2$ = load in pounds, whence, if P = the mean effective force on the steam piston in pounds per circular inch, we have $d = \left(\frac{341 h}{P}\right)^{\frac{1}{2}} = D$, the diameter of the steam piston in inches.

The quantity of work performed by one of the engines at Wheel Hope mine, Cornwall, in 1826, was as follows: —

Diameter of the cylinder	60 inches.
Load per square inch on the piston	8·37 pounds.
Length of stroke in cylinder	9 feet.
Number of strokes per minute	5½ feet.
Number of lifts, 1st, through 46 fathoms	5 feet.
2d, 11 fathoms	2 feet.
3d, 11 fathoms	2 feet.
Diameter of pump for 1st lift	15 inches.
2d ditto	12⅛ inches.
3d ditto	11 inches.
Consumption of coals	1242 bushels.
Number of strokes	261,890
Length of stroke in the pump	8 feet
Number of pounds lifted one foot high by one bushel of coals	46,838,246

Application of Steam Engines for raising Coals and Ores. — A double engine of from twenty to thirty horse-power is used, the size of the cylinder being such that the power shall be equal to the resistance when there is the greatest stress; consequently engines require more fuel to raise such bodies to the required height, as much is lost by the stoppages and changes in motion: from 3 cwt. to 7 cwt. is usually raised at a time, and 1 pound of coal is calculated to lift about 70,000 pounds of ore. The engine should work expansively, and be equalised by a fly-wheel, and regulated by a governor.

Application to Corn Mills. — The double expansive engine is usually employed, and with low-pressure steam it will grind 14 bushels of wheat for each bushel of coals, when working properly; but the average is perhaps about 11½ only. To dress a bushel of wheat, as well as grind it, per hour, is 31,000 pounds raised 1 foot per minute: the velocity of the circumference of the millstone should be 23 feet per second, and with that velocity a pair of 5 feet stones should grind 4 or 5 bushels per hour.

Application to Water Works. — For this purpose, where fuel is expensive, double engines with fly wheels are the most economical, and where it is cheap, single ones: in raising water care must be taken that the air-vessel should be in the direction of the motion of the fluid, for if placed on one side, the joints are liable to be torn asunder, the cranks broken, and the machinery disarranged, from the concussion which take place.

Application to Threshing Machines. — Engines of from four to six horse-power are used: the feeding rollers are 3½ inches in diameter, and make from 35 to 37½ revolutions per minute: the straw rakes are 3½ inches in diameter, and make 30 revolutions per minute: the diameter of the drum is 3 feet 6 inches, and makes 300 revolutions in a minute.

The quantity of wheat threshed by a machine with feeding rollers, 4 feet broad, varies from 12 to 24 bushels per hour, according to its quality, and the quantity of oats from 16 to 30 bushels. The power required is 100,000 pounds raised 1 foot per minute for threshing alone, and 133,000 when winnowing is applied; each inch of straw receives three strokes of the beaters, and the stroke is made with a velocity of 55 feet per second, or the beater should move 3300 feet per minute.

Application to Steam Boats.—The maritime engine is made more compact than that usually employed in our manufactories, and, in order to diminish its height, the working beams are placed below the cylinder on each side: in engines of 200 horse-power, the cylinders are made 5 feet in height, and 53 inches in diameter, in order to save room; the other portions of the engine do not materially differ from those we have already described. The shaft, upon which the paddle-wheels are fixed, is made to revolve by cranks placed upon it, in the same manner as the fly-wheel of a common engine: the paddle-wheels are made like the common undershot, and bear on their rims flat paddle-boards: the marine engine may be either condensing or high-pressure, but the low-pressure condensing is generally used.

Locomotives.—The general description of the locomotives on the London and Southampton line is as follows:—the engines have two horizontal cylinders, working to a double-cranked axle in the driving-wheels: there are six wheels; the diameter of the driving wheels is 5 feet 6 inches, and the others 3 feet 6 inches, each of which have a nave of cast-iron, bound with two hoops of malleable iron; the rims are also of the same metal, and well welded to the rim, round which is a tire $1\frac{1}{4}$ inch in thickness and 5 inches wide, the flange of which projects 1 inch; these wheels are all turned very accurately, and have a conical inclination: the cylinders are 13 inches in diameter, and have metallic spring pistons fitted into them, which make an 18-inch stroke.

The Boilers are cylindrical, 3 feet 3 inches in diameter and 8 feet long, and contain about 120 tough rolled brass tubes, $1\frac{5}{8}$ inch in diameter at one end, and $1\frac{3}{4}$ at the other, drawn on a mandrill; they are fastened to the boiler with steel hoops: the thickness of the tubes is No. 15. wire gauze, and the holes in the ends of the boiler are all parallel.

The Fire-box is of copper, $\frac{7}{16}$ of an inch in thickness, but where the tubes are fixed, the plate is $\frac{3}{4}$ of an inch in thickness: the width of the fire-box internally is 3 feet 6 inches; length 2 feet 6 inches, and depth from the roof to the top of the fire-bars 3 feet 4 inches; the water-spaces are 3 inches wide, and the roof and sides of the box are stayed with copper bolts, tapped and riveted.

The Axles.—The cranked axles are made of the best Backbarrow iron, $5\frac{1}{4}$ inches in diameter at the crank pin, and it is turned down to $3\frac{1}{4}$ inches for the outside bearings: the axles for the fore wheels are $3\frac{3}{4}$ inches, and for the hind wheels $3\frac{1}{4}$ inches in diameter; they are turned throughout.

The Framing.—The engine is provided with four inside stay and bearing frames of wrought-iron, with brass bearings to fit to the main axle on both sides of each crank, the axle being properly turned to suit these bearings, and the frames are connected with the fire-box and cylinder beds, which form stays for their support. The outside frames are made of well-seasoned ash plank, 3 inches thick and 7 inches deep, plated on both sides with quarter-inch best Low Moor plates. These frames are 3 feet 2 inches clear above the surface of the rails.

Feed Pumps.—There are two, made of brass, fixed at the side of the boiler, the water-spaces of which have an area of $2\frac{1}{2}$ inches clear.

The Chimney is covered with a wire cap, and all its bearings and journals are case-hardened, and its height is 13 feet from the rails.

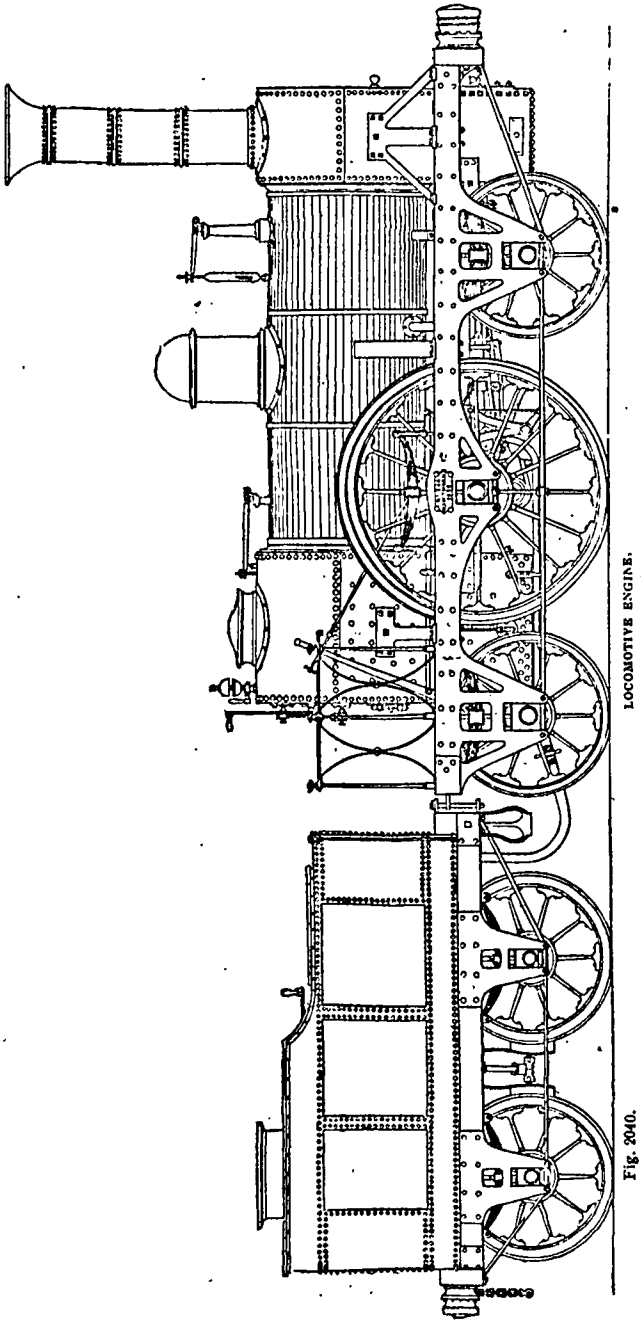
The Engine is worked by eccentrics, with single slide valves and steel facings, and there are two safety-valves, water-gauges, buffers, draw-bars, splash-boards, ash-pan, siphon cups, safety-bars in front, wood sheathing, brass ball and socket, communication pipes, steel springs, and all other requisites to complete their working order.

The Tenders have their frames made with well-seasoned ash timber, with transverse and diagonal braces well bolted together: the tank is of a horse-shoe form, and contains 700 gallons of water; it is made of iron plates, $\frac{5}{32}$ of an inch thick, and provided with cocks and pipes, to connect with the ball and socket feed-pipes of the engine: the wheels are of wrought-iron, 3 feet 6 inches in diameter, with wrought-iron tires $1\frac{1}{4}$ inch thick.

The tenders are also provided with springs, break, buffers, long elliptical spring chains to draw by, with a box of tools, oil-cans, shovel, and all other requisites to put it into a working state.

Locomotive Engines differ from the ordinary steam-engine in their arrangement, and may be said to consist of three several parts; the square box which contains the fire, the boiler and its tubes, and the portion in front, where the cylinders and chimney are placed.

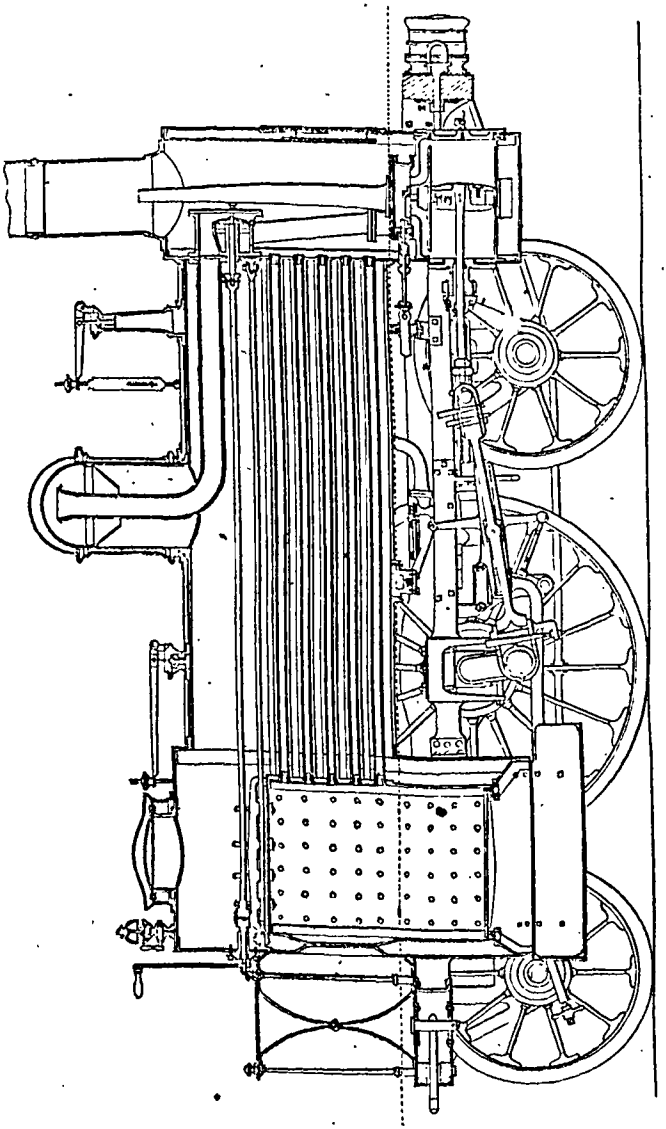
The usual construction is that with two horizontal cylinders, from 12 to 15 inches or more in diameter, fitted with single slide-valves and metal spring pistons, having a length of stroke from 16 to 18 inches. The fire-box is open only at the bottom, and placed at the back part of the engine; it is made of copper, and has a door to admit the fuel; the general dimensions may be said to be 30 inches in length, from back to front 40 inches in width, and the height from the iron grate-bars at bottom to the top 39 or 40 inches: the fire-box is entirely surrounded by water, except at the bottom, and where the opening is to admit the putting on the fuel. The space for the water is about 3 inches in width, and where it is in contact with the cylindrical portion of the boiler it is a little more.



LOCOMOTIVE ENGINE.

Fig. 2040.

The extreme width of the fire-box in such a case does not exceed 47½ inches, and the iron plates with which it is surrounded are in thickness about $\frac{7}{16}$ of an inch: the covering or



LOCOMOTIVE ENGINE, LONGITUDINAL SECTION.

Fig. 2041.

top, however, where greater strength is required, has four wrought-iron rods riveted to the upper surface, and the sides are held more firmly together by means of copper bolts, which are tapped and riveted. The aperture to admit the coals is usually formed by a ring of copper, and the iron plates of the casing are gathered in, and firmly riveted to it with copper rivets.

The boilers are of a cylindrical form, about 8 feet in length, and 3 feet or more in diameter; the ends are closed by circular iron plates, the lower half drilled with holes, in which from 70 to 140 longitudinal tubes of tough rolled brass are inserted by means of hoops of steel; the thickness of the brass out of which they are formed is that called No. 15 wire gauge; they are made truly cylindrical by drawing them through a mould: one end of these

tubes is open towards the fire-box, and the other towards the chamber in front, where the chimney is placed; there is another door which allows of the tubes being cleaned out when requisite. The iron used for the construction of the boiler is mostly Yorkshire plate, $\frac{3}{8}$ of an inch in thickness, or, where more strength is required, $\frac{1}{2}$ inch, as at the back, and at other parts only $\frac{5}{16}$ in thickness; the fire-boxes are lapped and riveted together as well as the boilers, care being taken that the action of the fire does not come too strong against the parts where the welding is made. Since the introduction of the tubular boilers few accidents have occurred from bursting; they were the invention of M. Seguin, an engineer at Annonay in France, who patented them early in the year 1828. The steam occupies the upper part of the boiler, from which it passes into a chamber by two pipes, each of which has three openings or apertures, to admit it before and behind the piston, as well as to escape up the chimney. The evaporation in the boiler is effected partly by radiant heat communicated to the water which encompasses the fire-box, and partly by means of the hot air transmitted through the tubes. It has been ascertained that 1 superficial foot exposed to the action of heated air, as that passing through the tubes, has no more than a third of the effect when the same area is exposed to radiant heat, or has the direct action of the fire: a locomotive in action, proceeding at the rate of nearly 19 miles an hour, was found to evaporate 55·82 cubic feet of water during that time, where the surface exposed to radiation was 43·12 superficial feet, and that to heated air 288·35 superficial feet: when a number of tubes of small diameter are made use of, the temperature of the air passing through them should be as nearly as possible that of the water in the boiler; there would then be little loss in that which passes off by the way of the chimney: but the heated air is much higher in temperature, which is partly rendered necessary, in the present locomotive, to maintain sufficient draught to carry on combustion.

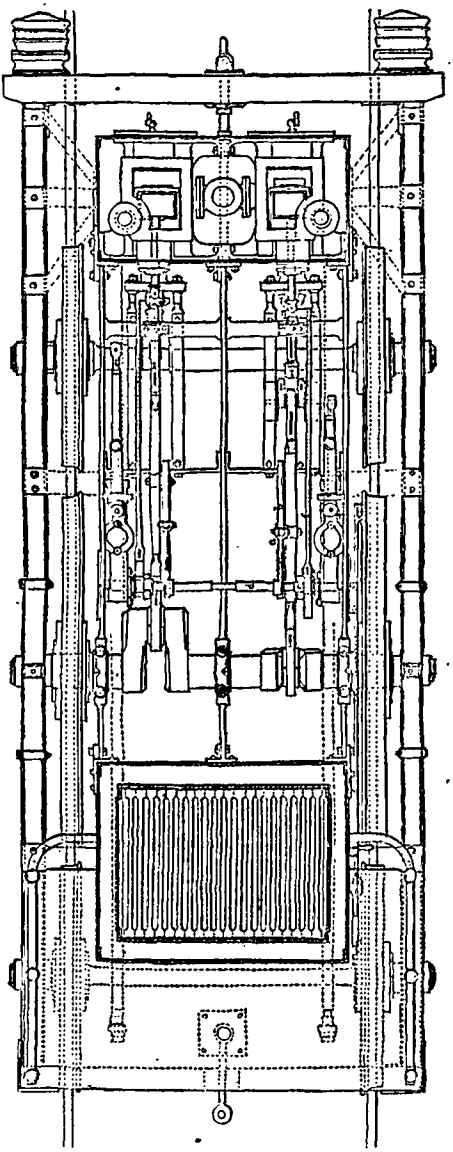


Fig. 2042. PLAN OF LOCOMOTIVE.

The Regulator Box (fig. 2044.) was first constructed by Mr. Watt; a spindle passes through one side of the box, on which a toothed sector moves as a centre, working a rack fixed to a brass valve accurately ground to its seat; the plug tree, part of which is shown under the valve box, alternately opens and shuts the valve by means of a pin acting on the bent lever, the upper arm of which works the toothed sector: this is the form usually applied to stationary double-acting engines, but for locomotives the contrivance shown in fig. 2045. is adopted; the steam is carried up into a hemispherically crowned cylinder, whence it descends to the regulator, where the communication is made with the two pipes connected with the

chambers above the cylinders, in which the pistons work; the uppermost rod, which passes longitudinally through the chamber of the boiler, where the steam is confined, has a handle at the end, which, when turned by the conductor or engine-man, moves the two discs alternately backwards and forwards, which cover the aperture of the two steam pipes; and this can be easily effected. The discs being fixed upon a horizontal rod, the cylinders can be either opened or closed at pleasure: it is important that these discs should press against the mouth of the pipes, which is partly effected by the steam and partly by spiral springs.

Safety-Valves.—The boiler has two safety-valves: their forms vary; the mitre valve, when shut, prevents the steam from escaping, and it remains closed as long as the steam is above the common pressure of the atmosphere, during which time it cannot escape: above the spiral spring is a plate attached to a perpendicular spindle, which passes through the top of the valve, where it has a screw-thread and nut; when this is turned it presses against the spring, and by forcing it downwards opens the valve, and allows the steam to pass off; any pressure may be put upon this valve, and when the steam is below that pressure, the attendant upon the engine observes the steam escape, and is then assured that it has not the requisite elasticity.

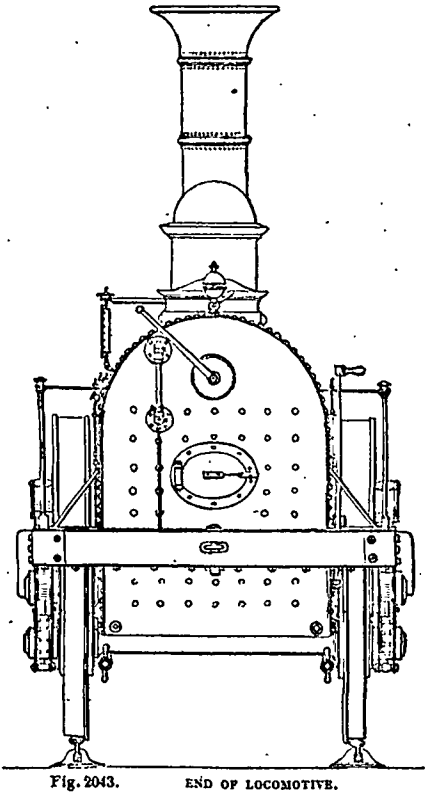


Fig. 2043. END OF LOCOMOTIVE.

The Water Gauge, attached to the boiler, is for the purpose of ascertaining the height at which the water stands; but generally a small cock is placed at various heights on the side of the boilers, which when turned indicates the level of the water. A glass

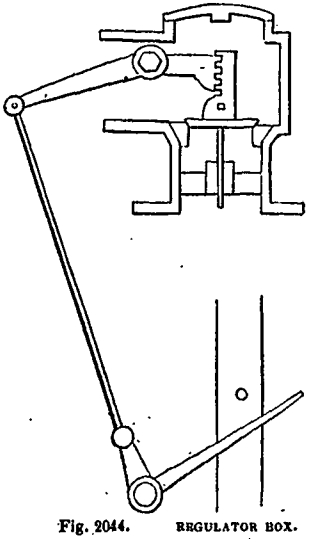


Fig. 2044. REGULATOR BOX.

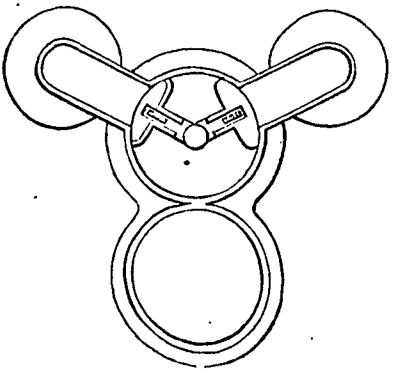


Fig. 2045. REGULATOR.

tube fixed in brass rims is attached to the boiler, having at the top a brass cock turned by a handle, and at the bottom another for letting off the water in the glass tube, after the level has been ascertained.

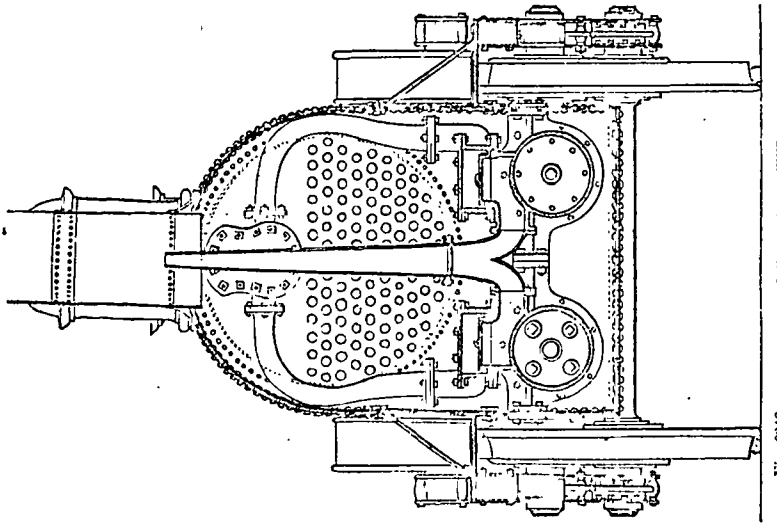


Fig. 2046. SECTION OF LOCOMOTIVE.

The Cylinders, which are placed in front, are attached to the framework of the boiler; they are surrounded by heated air, as they are within the front chamber, through which is the escape from the tubes to the passage of the chimney: in order effectually to prevent any water passing off with the steam from the boiler into the cylinders, the steam-pipe is carried up, as has been described, into a hemispherically crowned cylinder, and

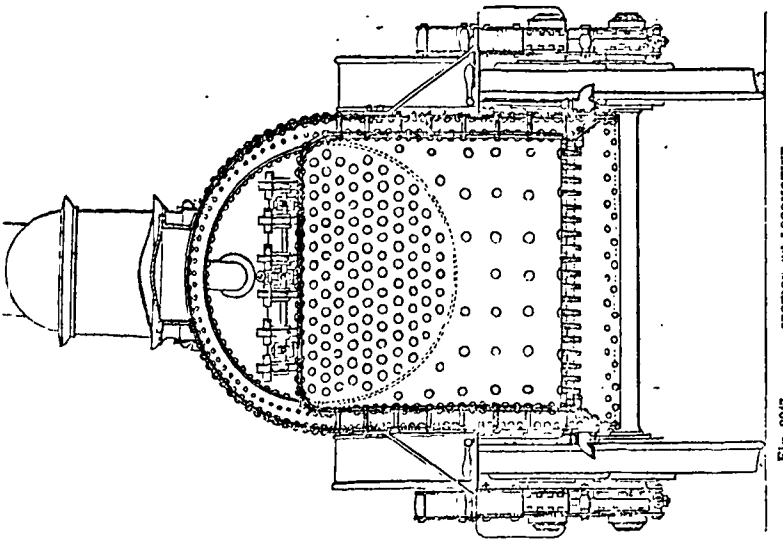


Fig. 2047. SECTION OF LOCOMOTIVE.

whatever water boils or bubbles up cannot reach the funnel mouth, intended only for the passage of steam; before the steam is admitted by the regulator to the pipes, which conduct it to the cylinders, it enters a small chamber, which is an admirable contrivance, and perhaps one of the most important parts of the whole machine. These chambers are placed above the cylinders, and within them is a movable box or slide, which, as its motion is either backwards or forwards, effects a communication with the steam-

chambers, and with one or other of the openings which lead to the front or back of the piston, giving the first impulse to the moving powers. When the steam is admitted through the regulator into the pipes which conduct to the steam-chamber or valve-box, it there presses the sliding valve lightly upon its horizontal plane; this, however, is moved backwards and forwards by means of a rod, having four sheaves or rings fixed upon the axles of the driving-wheels, upon false centres or eccentrics, so that at each revolution of the axle the slide is moved backwards and forwards, admitting the steam both before and

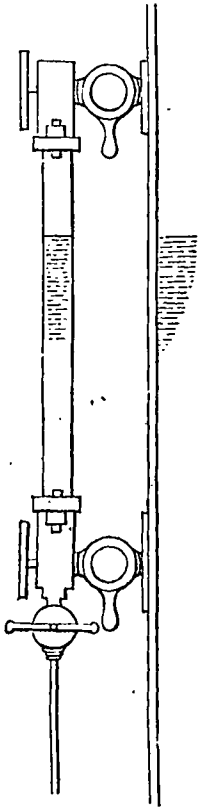


Fig. 2048. WATER GAUGE.

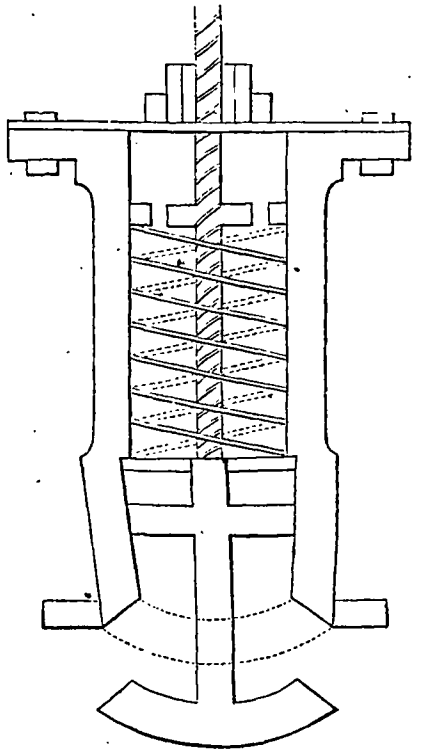


Fig. 2049 MITRE VALVE.

behind the piston. Thus an alternate motion is kept up by the slide passing, first, over one opening, then the other; the steam passes by the third aperture into the chimney, where it causes an additional draught to the fire. The motion given to the slide, however, is a little in advance of the required stroke of the piston, it being necessary that the steam should be admitted before the piston commences moving, so that it may exert its full power upon it; and this is effected by giving a lead to the slide The eccentric attached to the

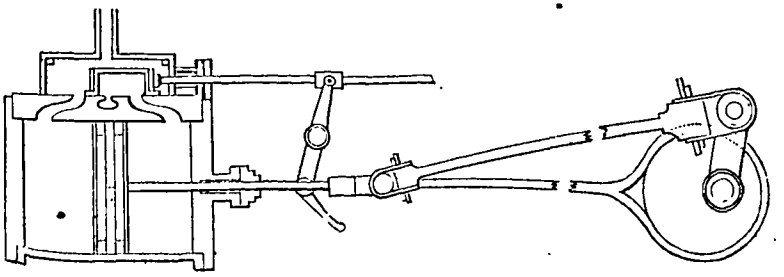


Fig. 2050. SLIDE VALVE AND ECCENTRIC.

axle of the wheel, which as it turns pushes and draws the rod of the slide, does the duty of a crank, converting the circular to alternate motion, as far as the slide is concerned, and alternate into circular, as regards the axle of the engine. The slide, however, not being exactly in the same plane with the axle, the motion is not directly communicated to the

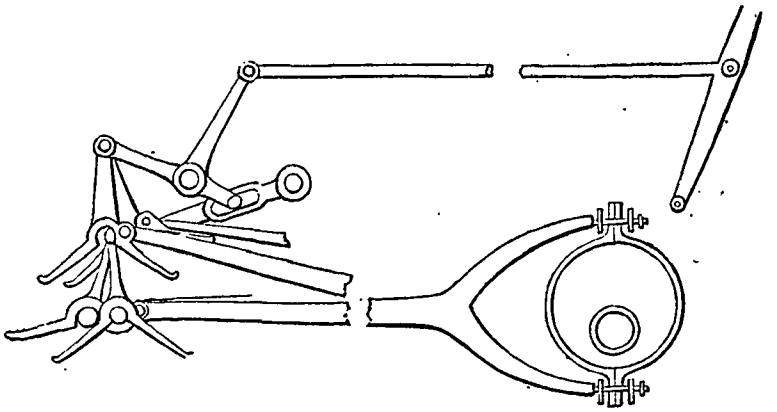


Fig. 2051. ECCENTRIC SLIDE VALVE, SIDE VIEW.

rod by the eccentric, but by a cross axle, and the two arms affixed to it; so that when the eccentric goes back, the slide rod is made to advance: there is an instant during the time the slide is in progress that all the passages are shut, and this is whilst the piston is changing its direction; to obtain a maximum effect, the steam requires to be shut off before the piston has reached the extremity of the cylinder, and the aperture on its other side should be partly opened before its change of motion takes place.

The Drivers are those portions of the engine which serve to change its movement: this is performed by disengaging the eccentric from one, and carrying it to the other; so that the director of the locomotive can at pleasure cause it to advance or retire. The drivers are fixed on the axles on opposite sides of the eccentrics, which being pushed by means of a lever can be thrown either into or out of gear; so that to change the motion it is only

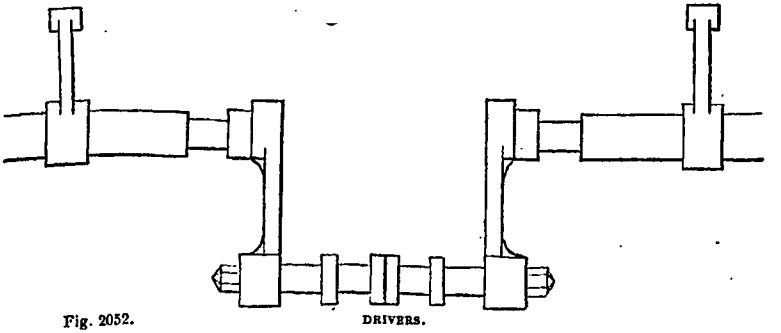


Fig. 2052. DRIVERS.

requisite to lift one set of forked arms from off one set of weight bars, and replace them on the other, which is performed by a handle, working on a fulcrum, and moving the arm attached to it: this also works a small pin fitting into the oblong groove of another lever, and moves the forked arms upwards; at the same time the lever is depressed by the pin, and with it the forked arms below. The piston-rods slide on guides, and preserve a regular horizontal motion, and from them is communicated a rotary movement to the axles of the hind wheels, the alternate being transformed into circular motion by means of a crank on the axle.

There is great danger in cranked axles from their breaking, which with four-wheeled engines might occasion considerable damage; this has repeatedly happened, generally from bad welding: in one instance, on the London and Birmingham Railway, an engine was discovered to have been running for some time with a broken axle, arising from the eccentrics being keyed on to the weakest part of the axle, and only two-thirds of its section being soundly welded.

Pumps for the supply of water to the boiler are usually two in number, placed beneath the piston-rod of the cylinders; they suck a portion from the tender, and then force it into the boiler: these pumps have spherical valves, made of metal, which rise within a cylinder having four apertures for the passage of the water.

To fill the boiler a square pit should be sunk, large enough to admit a pair of 8 feet wheels, fixed on an axle similar to the carriage wheels; they should have no flanges, and their circumference should come up through the rails, and be made to lock at pleasure. When it is required to pump water into the boiler, the engine must be brought with its driving wheels directly over those in the pit, and these latter being unlocked, the steam is let gradually on, and the pumps worked as long as is necessary for filling the boiler, without the engine advancing from where it was placed.

The Steam Whistle is fixed to the boiler; by turning the handle, the cock placed in the pipe is moved round; the steam issues with such violence that when it enters the brass hemispherical cup at the top, it strikes in its passage the thin edges of a horizontal brass plate, producing a shrill and loud whistle as it escapes.

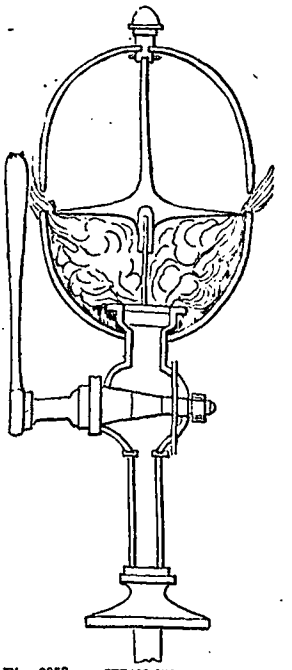


Fig. 2053. STEAM WHISTLE.

We shall now give the dimensions of some of the most approved locomotives: those used upon the Liverpool and Manchester line have cylinders 10 inches in diameter, and a length of stroke of 16 inches; their boilers are 8 feet in diameter, and 6 feet in length, within which are inserted 90 tubes, 2 inches in diameter: the fire-box is 24 inches in length, and 36 in width, with a similar height. The area exposed to radiant caloric is 25 feet 6 inches superficial, whilst the area of the fire-grate is 6 feet: the superficial area of the tubes in contact with the heated air is 283 feet.

In an engine where the diameter of the cylinder is 11 inches, and the length of stroke 16 inches, the boiler is 3 feet in diameter, 6½ feet in length, and contains 132 tubes, 1⅝ inches in diameter; the length of the fire-box is 22 inches, the width 40 inches, and the height 34 inches. The area exposed to the radiant heat is 32¾ feet; that of the fire-grate nearly 7 feet, and the area of the tubes exposed to the contact of the heated air is 379 feet.

An engine with 12-inch cylinders, and with the same length of stroke, has a boiler 3 feet in diameter, and 7 feet 9 inches in length, with 104 tubes, 1⅝ in diameter: the fire-box is 24½ inches in length, 43 inches in width, and 37 inches in height above the fire-bars. The area exposed to the radiant heat is 39¾ square feet; that of the fire-grate is 7½ feet, and the total area of the tubes 354 feet.

An engine of 14-inch cylinders on the Leicester Railway, and 18-inch stroke, has a boiler 42 inches in diameter, 90½ inches in length; 97 tubes 2⅛ inches in diameter; the length of the fire-box is 26 inches, the width 41, and the height 44 inches: the area exposed is 46 superficial feet, and that of the fire-grate nearly 7½ feet. The area of the tubes in this engine is 420½ feet: the total weight, when in working trim, 10 tons 8½ cwt.; the dimensions of the steam-way to the cylinder are in length 7 inches, and width 1½ inches.

An engine on the Newcastle and Carlisle line, with 15-inch cylinders, and a length of stroke of 16 inches, has its boiler 45 inches in diameter, 8 feet 6 inches in length, and 145 tubes, 1⅝ inches in diameter. The fire-box nearly 39 inches in length, 41¼ in width, and 44¼ inches in height: the area exposed to radiant heat 60 feet 4 inches, and that of the fire-grate 11¼ feet superficial. The area of the tubes in contact with the heated air nearly 547 feet.

An engine on the Great Western, with 16-inch cylinders, and a stroke of 16 inches, has its boiler 4 feet in diameter, and 8 feet 6 inches in length; the number of tubes 167, all 1⅝ inches in diameter. The fire-box in length 41¾ inches, in width 47, and in height above the bars of the grate 45¾ inches. The area exposed to radiant heat 70 superficial feet, and the area of the fire-grate 136 feet. The area of the tubes exposed to the heated air was 54¾ square feet.

The above engines were constructed by R. Stevenson and Co., at Newcastle-upon-Tyne; the following were made by Messrs. R. & W. Hawthorn of the same place. An engine with 12-inch cylinders, and a length of stroke of 16 inches, had the diameter of the boiler

36 inches, and length 89; in this were 64 tubes, 2 inches in diameter. The length of the fire-box 21½ inches, width 41, and height above the bars 38½ inches. The area of the fire-box exposed to radiant heat 37 square feet, and the area of the fire-grate 6 feet 1 inch, and that of the tubes 262 feet 6 inches. The weight of this engine without water in the boiler was 145 cwt., and when filled 170 cwt.; the length of steam-way to cylinder 6 inches, and width 1¼ inch.

A 12-inch cylinder, with an 18-inch stroke, made for the Paris and Versailles Railroad, had a boiler 39 inches in diameter, and a length of 8 feet, with 121 tubes, 1⅝ inches in diameter. The length of the fire-box 30 inches, width 41½, and height above the bars 40¾ inches; the area of the fire-box exposed to the heat 46 superficial feet, and that of the fire-grate 8 feet 7 inches. The area of the tubes in contact with the heated air was 428 feet 3 inches; its weight, without water, 172 cwt. and with, 200 cwt.

A 13-inch cylinder, made for the Grand Junction, with an 18-inch stroke, had the boiler 39 inches in diameter, and 8 feet in length: there were 130 tubes, 1⅝ inches in diameter: the length of the fire-box 32 inches, width 41½, height above the bars 42½; the area of the fire-box 49¼ superficial feet, and that of the fire-grate 9 feet 2 inches; the area of the surface of the tubes 460¼ feet. The weight of this engine without water, 175 cwt., and 203 cwt. when filled.

A 14-inch cylinder, and 18-inch stroke, on the Newcastle and Carlisle line, had its boiler 42 inches in diameter, and 8 feet 6 inches in length, which contained 115 tubes 2 inches in diameter. The length of the fire-box 36, the width 41½, and the height above the bars 44 inches; the area of the fire-box 54 feet, and that of the fire-grate 10 feet 4 inches. The area of the tubes 532 feet, and the weight of the entire engine, without water in the boiler, 205 cwt., and with, 235.

A 16-inch cylinder, on the Great Western, with a length of stroke of 20 inches, has its boiler 44 inches in diameter, and 8 feet 8½ inches in length: there are 135 tubes, 1⅝ inches in diameter. The length of the fire-box 44½ inches, width 60, and height 47; the area of the fire-box 108½ feet, and that of the fire-grate 17 feet 2 inches; the area of the tubes exposed 516 feet.

The locomotives constructed for the Southamptom Railway by the Messrs. Rennie, of Holland Street, London, combined all the improvements that had been made up to that period. The diameters of the cylinders were 13 inches, the length of the stroke 18 inches, and the area of each of the cylinders was 132¾ inches; there were 118 brass tubes, and the heating surface 493 feet: the area of the fire-grate 9 feet 4 inches, containing 14 cube feet of fuel: the water in the boilers was a little more than 36½ cube feet, and the space for the steam was 32¼ cube feet. The water evaporated in an hour, with steam equal to 50 pounds pressure on the safety-valve, was 63½ cube feet. The following table will show the other proportions: —

Water supplied by each pump, per stroke	56·5 cube inches.
Diameter of the driving wheels	5 feet 6 inches.
of the small	3 feet 6 inches.
Cubic content of water in tender tank	118·8 cube feet.
Weight of ditto when full	3·3 tons.
Time which the water in tender will supply engine	1·87 hours.
Coke fuel necessary to evaporate all the water in the tank	9½ cwt.
Number of revolutions of driving-wheel per minute, at 30 miles per hour	152·76
Velocity of each piston in feet per minute, at the average speed of 3 miles per hour	458·28
Area of steam pipe	9·62 square inches.
of steam ports	9·56 —
of eduction pipes	14·87 —
of blast pipe mouth	7·06 —
of chimney	159· —
of radiating surface	6696· —
of communicating surface	70960· —
of total heating surface	77650· —
Total resistance to the motion of the pistons per square inch on its surface	38·4 pounds.
Volume which the whole steam produced per hour will occupy at the reduced pressure of the preceding resistance	46695 cube feet.
Ratio of the preceding volume to that expended in effecting a single stroke of one piston, number of strokes per hour	32427
Corresponding number of revolutions of driving-wheel,	8106·75 per hour.
Distance travelled per hour	26½ miles.
Weight of the engine without water	11¼ tons.
Ditto of tender	5⅛ —

The velocities of these engines have frequently exceeded 41 miles per hour, and the safety-valve is so constructed as to liberate the steam in an admirable manner, the principle being to diminish the resistance in proportion to the opening of the valve, contrary to that practice where springs and levers are used, the improved valve being made capable of regulation for any intensity of resistance.

A locomotive engine and tender made by Messrs. Hawthorne for the Versailles line has the

Diameter of cylinders	12 inches.
Steam way to cylinder	length $6\frac{1}{2}$, width $1\frac{1}{4}$ inches.
Length of stroke of piston	18 inches.
Boiler 8 feet long, 39 inches in diameter, contains 121 tubes $1\frac{5}{8}$ inches in diameter, exterior length of tubes 8 feet, and presenting a surface exposed to contact with heated air of 428·40 square feet	
Fire-box	length 30, width $41\frac{1}{4}$ inches.
Height above the bars	$40\frac{3}{4}$ inches.
Area of fire-grate	8·59 square feet.
presenting a surface exposed to radiant caloric of	46·16 square feet.
Quantity of fuel contained in fire-box to the height of the lowest row of tubes	1360 cube feet.
Diameter of chimney	14 inches.
The wrought-iron driving wheels	$5\frac{1}{2}$ feet diameter.
supporting wheels	$3\frac{1}{2}$ feet diameter.
Weight of engine, without water, in boiler	8 tons 12 cwt.
with water,	10 tons.

Consumption of Fuel.—When coals are used the same quantity is required as of good coke, which varies with different engines from half a pound to a pound per mile for every ton of load: the latter is perhaps nearest the truth upon level lines.

In locomotive engines the power does not depend altogether upon the diameter of the cylinders, a certain quantity of steam being produced each moment; if the diameter of the cylinder be increased, the number of strokes will be diminished, or the steam will have less elasticity; and if the diameter be less, then a greater elasticity or pressure per square inch is obtained, or an increased number of strokes: the quantity of steam being limited, the power of the engine depends entirely upon the number of times the cylinders can be filled during a minute, or the quantity of steam that can be generated or water evaporated in a given time. The elastic force of the steam is also partly diminished before it reaches the cylinders, by being obliged to pass through the small apertures of the pipes: and the pressure upon the piston is less than against the steam-valve in the boiler, which is still further diminished when the engine increases in velocity.

The Killingworth engine had a boiler 9 feet 2 inches in length, and 4 feet in diameter; within it was an elliptical tube which contained the fire, 2 feet 4 inches broad, 2 feet high, and 4 feet 8 inches long. The area of the fire-grate was nearly 13 square feet; the number of tubes 43, the radiant surface $22\frac{1}{2}$ square feet, and that of the communicative surface 101 feet 6 inches. The volume of heated air which passed through the tubes was equal to 135 square inches; the load 60 tons, exclusive of the tender, and the velocity upon a level road 9 miles per hour. The quantity of water evaporated per hour in this instance was 279 gallons, and of coal consumed $14\frac{1}{4}$ pounds for every cube foot of water converted into steam.

By another experiment it was found that the same engine with a load of 40 tons, travelling at the rate of 9 miles per hour, evaporated 40 cube feet of water, or 247 gallons per hour, with about 13 pounds of fuel for each cube foot evaporated: in one of the early experiments made at Liverpool, the Rocket engine, whose fire-grate contained an area of 6 superficial feet, a radiant surface of 20, a communicative surface of 118 square feet, with a load of 40 tons, going a velocity of 13 miles an hour, evaporated during that time only 30 cube feet of water, which shows the improvements that have been made since that time. By Mr. Watt's experiments, it required 8 feet of surface to be exposed to the direct action of the fire to evaporate a cube foot of water in an hour, and 10 cubic feet were converted into steam with 84 pounds of coal; in many locomotive engines, it requires upon an average 19 pounds of coal to convert a cube foot of water into steam, which is more than $2\frac{1}{4}$ times Mr. Watt's estimate; there is therefore at present in some instances a very great loss in the application of fuel to locomotives: upon the Killingworth railway the average of several years' consumption for the engines employed was 2·12 pounds per ton per mile; on the Darlington railway, 2·16 pounds; upon the Bolton and Leigh railway 2·03 pounds per ton per mile.

Railway Hydraulic Traversing Frames, used at the Bristol terminus of the Great Western, for moving the railway carriages from one line of railway to the other, without the use of the turntable.—This machine is a wrought-iron frame, strongly braced and tied together laterally and diagonally; at each of the four corners is placed a cast-iron hydraulic press,

connected with two force-pumps by means of copper pipes and gun metal nozzles: upon the plungers of the four presses rest two additional frames, which are attached to the one below by four sets of parallel motion bars, so that they rise truly perpendicular. When it is required to move a carriage from one line of rails to another, the apparatus is pushed under it, and when the carriage is in a position directly over the frame, the large pump which acts upon the four hydraulic presses raises the frames until they arrive under the axles of the carriage wheels; after this the smaller pump is worked, which raises the flanges of the wheels clear of the rails: when the carriage is moved, a stopper is unscrewed, which permits the water to flow from the presses back again into the cistern, and the carriage is lowered to the rails; the apparatus is then drawn out and ready to be again made use of; the cost of this machine is about 220*l*., and was designed by Arthur John Dodson.

Locomotive Engines on the London and Birmingham railway are all constructed with four wheels and in one uniform pattern; the passengers' engines have 12-inch cylinders, and the pistons an 18-inch stroke; the driving wheels are in diameter 5 feet, and the carrying wheels 4 feet: the engines employed for the transport of goods have 13-inch cylinders, and a stroke of 18 inches also, but in these all the wheels are 5 feet in diameter; a passenger engine with its coke and water in the fire-box and boiler weighs 9 tons 13 cwt. 1 qr., and the other 11 tons 13 cwt. 1 qr.

The framing of these engines is fixed inside the wheels, which allows of its being better attached to the boiler; the whole is of wrought-iron; the cylinders are also made fast to this frame by strong wrought-iron bars, as are the cranks and fore axles: when the engine is either advanced or made to retrograde, the motion is conveyed through the framing alone, and no strain whatever is produced upon other parts. There are two bearings inside the wheels alone on the axles; and the bushes in which the axles run are so fitted to the frame that the springs have a vertical movement and no lateral action; they are so arranged with a flange at their sides, that if an axle were to break, they would support the engine for a time.

Two of these Engines, made by Edward Bury, in the year 1839, performed a journey of 700,000 miles at the following cost: for the first six months the cost of conveyance of passengers was $\frac{253}{1000}$ of a penny per ton per mile; and for the second 6 months $\frac{380}{1000}$; and for the first six months of the other engine carrying goods, the total cost per ton per mile was $\frac{293}{1000}$ of a penny, and for the second six months $\frac{227}{1000}$ of a penny: this calculation included the cost of coke, oil, tools, wages, repairs, and general charges.

Locomotive Engines, manufactured by Mr. Norris, of Philadelphia, and sent by him to the Grand Junction Railway: the construction of these engines was simple; their boilers were horizontal; each contained 78 2-inch copper tubes, 8 feet long each, with an iron fire-box: the cylinders were 10½ inches in diameter, and were slightly inclined downwards, and the piston-rods were made to work outside the wheels, so that cranked axles were not required: six wheels supported the frame, and the two driving-wheels were 4 feet in diameter, placed close before the fire-box: the other four wheels were 30 inches in diameter, and attached to a truck, on which rested the front end of the boiler: this truck, by means of a centre-pin, was connected with the frame, which was made to turn freely, and with very little stress, along any curve in the rails.

The weight of one of these engines, when the boiler and fire-box were full, was 9 tons 11¼ cwt.; that of the tender, with 21 cwt. of coke and 520 gallons of water, was 6 tons 4¼ cwt.; when empty it weighed only 8 tons: 62 pounds per square inch was the limits of working pressure of the steam on the boiler, and when the engine passed a plane with a rise of 1 in 330, with a load of upwards of 100 tons, the speed varied from 14 to 22 miles in an hour, and on a plane of 1 in 177, from 10 to 14 miles per hour. The rise of the gradients from Liverpool to Birmingham is 620 feet: and from Birmingham to Liverpool 380 feet, exclusive of those in the Liverpool and Manchester Railway. In seven journeys of 596 miles up to Birmingham, the engine conveyed 682 tons, evaporating 12,705 gallons of water, and consuming 265¼ cwt. of coke: in seven journeys the other way, or returning, the same engine conveyed 629 tons gross, evaporating 12,379 gallons of water, and consumed the same quantity of coke.

The price of these engines complete, including the duty, was about 1600*l*: they were so well adapted to travel over a curved line, that they have gone at a speed of 20 miles per hour round one of 10 chains radius; when on a straight line they travelled often 40 miles per hour, and appeared less likely to be thrown off the rails than the ordinary locomotives.

CHAP. XXII.

TIMBER AND ITS PROPERTIES.

By the civil engineer this production is required to be sound and properly seasoned; its durability depends upon the absence of those natural juices which possess a saccharine quality, undergo the process of fermentation, and destroy the substance as well as strength of the timber.

The various trees of the forest are composed of bark, wood, and pith, and spring from the acorns or seed which each bears: early in the spring a tender shoot breaks the ground, which by the end of the year has extended, enlarged, and hardened into a ligneous substance, terminated by a bud, which in the following year throws out a second shoot, but of greater strength and larger than that of the preceding year; this process continuing year after year enables the tree to acquire its full growth.

A cylindrical ring encloses the pith in its early stage, which is surrounded by the bark, and if a longitudinal section of the plant be made, we perceive medullary rays traversing the wood; the bark and the alburnum or woody matter have each a layer deposited every year, whilst the tree is in a growing state; these layers are both formed from a secretion called *Cambium*, deposited by the succulent vessels of the bark, and the medullary rays between the wood and the bark, which secretion is prepared by the leaves and transmitted through the bark; the new liber and alburnum formed by this gelatinous fluid are by a process of nature transformed into cells and layers, the diverging as well as concentric being produced simultaneously; these layers of wood obtain in a few years greater density, from a deposition of woody matter in the cells, which increases until the tree has arrived at maturity: each succeeding year of growth a hollow elongated cone may be imagined to cover the ligneous productions of the former years; the circles, which are distinguishable when the tree is cut down at its base, exhibit the number of these cones, as well as the increase of growth each year.

The pith and the bark in young shoots are in contact; and the former, composed entirely of cellular tissue, is at first filled with a watery fluid, and afterwards with air, becoming dry before the first layer of wood is perfected: the form of its cells is usually hexagonal; but as the age of the plant increases, they undergo some change; a horizontal communication of the most perfect kind continues to be maintained between the pith and the bark, although their separation is annually increased by the succession of concentric rings deposited. Medullary rays, or the silver grain, which are flattened masses of cellular tissue, consisting of oblong cells horizontally arranged, effect this by separating into wedge-shaped vertical plates the rings of zones of wood as they form, and thus keep up a connection between the pith and the woody tissue and vessels they are combined with on the outside.

The bark, or outer cuticle, is a thin membrane extending over the entire surface of the plant, spreading its members like a net, the form of which varies in different plants; this is divided into four distinct parts: the epidermis, the cutis, the cellular, and the liber or inner bark; the cutis consists of two layers, the outer of which is the epidermis, and the inner a composition of transverse cells, of a varied structure. The longitudinal fibres of the bark vary, but are formed of hollow tubes, which convey the sap downwards, for the purpose of increasing the solid contents of the tree. The bark itself is annually reproduced, and the old layers pushed outwards: there are no annular or spiral vessels; the cells contain occasionally a secreted fluid, which, in some instances, is useful to the arts.

Elasticity, extensibility, contractibility, permeability to fluids and gaseous matters, are the chief elementary organs of trees; which, by their cellular tissue, transmit their food in all directions: by it the sap is circulated, and the medullary rays formed, which convey the juices from the bark to the centre of the stem; the bark itself is composed of it, as well as the leaf, which exposes to evaporation, light, and atmospheric action the parenchyma in which the sap is diffused. The woody tissue, destined to convey the fluids upwards and downwards, gives firmness and elasticity to the various parts: and the sap-wood next the bark, containing all the nutritive matter to be converted into leaves, buds, and heartwood, may easily be supposed to be acted upon by a variety of causes, and be most subject to decay: when its vessels have lost their juices, and it is compressed into heartwood, its use is then to give support to the tree.

Wood is formed, according to Linnæus, from the pith, and by other naturalists it is supposed to be produced by a change of the liber of the previous season: by Du Hamel, that it is deposited by the secretion called *Cambium*, which is found between

the bark and the wood, and in process of time converted into cellular and woody tissue, and that the alburnum derives its origin from the bark, and not from the wood; whilst others imagine that wood and bark are independent formations out of *cambium*. The central part of the tree is the best timber, for the last layers or rings have their vessels larger and less compressed, being full of juices, and consequently of less density.

Different Species of Timber used in Construction. — *Acacia*, (*Robinia pseudo-Acacia, or Locust Tree,*) forms heartwood at an early stage; when it arrives at maturity it measures nearly 2 feet in diameter; in the pleasure-ground it is a very ornamental tree, and of rapid growth. When used for construction it is durable, and well adapted for sills and wall-plates, its lateral strength being greater than that of oak, in the proportion of 1 to ·75: it is heavier, harder, and tougher than the best oak, and more elastic, not readily breaking to any strain: for posts placed in the ground it will endure sound a long time; it is valuable for fences and treenails for ship-building. The weight of acacia is one-sixth greater than that of oak.

	lbs.	oz.	
It weighs when newly cut	63	3	per cube foot.
half dry	56	4	—
quite dry	48	4	—

Its strength is as, compared to oak, 1427 to 820, and its elasticity as 21 to 9: its lateral strength has perhaps been too highly rated.

Alder (*Alnus*). — This tree has the property of enduring a long time under water, which renders it valuable for piles and water-pipes: it has a fine and close texture, is of a beautiful colour, works easily and well, and has been much used by the joiner and cabinet-maker.

	lbs.	oz.	
It weighs when green	62	4	per cube foot.
half dry	48	8	—
quite dry	39	4	—

The charcoal obtained from it is valuable for gunpowder, and 1000 lbs. of its ashes yield 65 lbs. of potash.

Ash (*Fraxinus excelsior*) grows to a large size, with a straight trunk; its wood is very elastic, and joists cut out of it bear before breaking a greater weight than almost any other variety of British timber. The wood when young is very flexible, and easy to work; but after it has undergone the process of seasoning, it is both tough and hard, and is then more used by the wheelwright than the carpenter. When subject to alternate dryness and moisture it is not durable, and if cut down when full of sap the worm soon attacks it: its quality is much altered in different soils.

	lbs.	oz.	
When green it weighs	64	9	per cube foot.
dry it weighs	49	8	—

Beech (*Fagus sylvatica*) is described by Pliny as one of the thirteen species of trees bearing mast or acorns; on a chalky soil it acquires a prodigious size, and is the finest tree of the forest: its timber is smooth and hard, its transverse fibres very obvious, sometimes forming distinct and dark lines, and it is highly useful for various purposes. The worm attacks it speedily, if not freed from sap, which is often done by steeping it in water, and then exposing it to smoke: when beech is constantly under water, it is very lasting, and therefore well adapted for piles; in a dry state and much exposed, it will split and crack.

	lbs.	oz.	
When green it weighs	65	13	per cube foot.
half dry	56	6	—
quite dry	50	3	—

Its ashes are productive of potash, 100 lbs. of green wood producing 1 lb. 10 oz.

Birch (*Betula alba*) has its wood tinged with red, and a moderately fine grain; when the tree has acquired its full growth, the timber is exceedingly hard, but not very durable; it works better in a green state than when perfectly seasoned and dry.

	lbs.	oz.	
When green it weighs	65	4	per cube foot.
half dry	56	6	—
dry	45	1	—

In a tree 60 years old, perfectly dry, a cube foot only weighed 36 lbs. 13 oz.: 1000 lbs. weight of this wood burnt in a green state yields 1 lb. 4 oz. of potash, which is most abundant in the bark and spray.

Box (*Buxus sempervirens*) is a valuable wood, of a yellowish colour, close grained, very hard and heavy; it cuts better than most others, is susceptible of a fine polish, and is very durable; it is much used by turners and mathematical instrument-makers, and by the wood-engraver almost exclusively.

Cedar (*Cedrus pinus*) grows to a great size; the timber is resinous, of a reddish white colour, light and spongy in its texture, easily worked, but apt to shrink and warp, if great attention be not paid to the seasoning; the annual rings are distinctly marked, and apparently consist of two layers, one narrow and hard, the other three or four times its thickness, and softer: it was exceedingly valued by the ancients for its durability and other properties.

Pliny asserts that the beams of the Temple of Apollo at Utica, which were of Numidian cedar, had endured 1178 years: its resin or gum was considered to possess the quality of preserving any matter from decay that had been steeped in it; the leaves of the papyrus, rubbed with it, Vitruvius says, were never attacked by insects. The wood is odoriferous, and admirably adapted for joiners' work: it is the lightest of resinous woods, and containing but a small quantity of resin: its weight is said to be 29 lbs. 4 oz. per cube foot, according to one authority; 42 lbs. 14 oz., and 57 lbs. by others: as a mean, it may, perhaps, be taken in a dry state at 42 lbs., or a little more.

Cedar, Indian (*C. Deodara*), a native of the Indo-Tartaric mountains, grows to a very large size, and is a very compact wood, strongly impregnated with resin: the hardness and the fineness of its grain occasion it to be much used by the Hindoos for the purposes of building, and when constantly exposed to the weather, its durability is considerable: bridges constructed of it, though occasionally exposed to the action of the torrent, have endured for 500 years.

Chestnut (*Castanea*).—This timber, when found in old buildings, has been frequently mistaken for oak, but the pores in the alburnum of the latter are generally much larger, more numerous, and very distinguishable, whilst those of the chestnut are irregular, and scarcely discernible to the naked eye; there is also an absence of the tranverse septa, which distinguishes the oak: there is, however, a species of oak, much used in the middle ages for the carpentry and roofs of halls and chapter-houses, which in colour and texture bear a close resemblance to chestnut; this species has a smooth bark, large leaves, and its wood rather softer than that of the ordinary oak, which might occasion it to be preferred for carved work, or where delicacy of execution was required; but whichever material was selected, great care was taken to admit the air freely, as well as to protect it from the weather, precautions as important as the proper selection and requisite seasoning of the timber. The cohesive force of the chestnut varies from 9670 to 12,000 lbs. per square inch when dry.

	lbs.	oz.	
The weight of the chestnut when green is -	68	9	per cube foot.
Ditto dry -	41	2	—

Horse Chestnut is a soft wood, and not applicable to any purposes where strength is required; in the open air it has little durability: it has been employed for water-pipes, when it can constantly be covered with earth.

	lbs.	oz.	
The wood, when newly cut, weighs - -	60	4	per cube foot.
Ditto dry - - - -	37	7	—

Cypress is remarkable for its fine grain and durability, and by some is supposed to be the Gopher wood used in the construction of the ark: this evergreen tree grows with a straight trunk, and its wood is harder than that of the pine, the colour partaking of a yellowish red with dark veins: in consequence of its not being subject to injuries from the worm, it was said to be incorruptible, and was much employed by the ancients for statues, in the construction of temples, and the gates of their public buildings: those removed from St. Peter's, when the bronze gates were introduced, had previously served to adorn the basilica of Constantine. In Egypt this wood was used for mummy cases; it is less affected by exposure to the atmosphere than cedar.

Elder.—The wood of this tree, when old, is very hard and adhesive, of a fine yellow colour, and susceptible of a high polish; in a dry state a cubic foot weighs 42 lbs. 3 oz.

Elm (*Ulmus*).—The *campestris* is the most durable and the hardest of the five English species; the *suberosa* not so valuable; the *montana*, or broad-leaved, is that most commonly produced in Europe; the *glabra*, or wych elm, is used by wheelwrights; and the *major*, or Dutch elm, is of an inferior quality. The elm, either in a perfectly wet or dry state, is very durable, and is admirably suited for planking or piling under water, enduring six or seven centuries. The wood is porous, cross-grained, has no large septa, shrinks in drying, both in length and breadth, is difficult to work, but will not readily split when nails or bolts are driven into it.

	lbs.	
The wood of the campestris, when green, weighs -	70	per cube foot.
ditto dry -	48½	—

The cohesive force of a square inch varies from 6070 to 13,200 pounds: it is rich in alkaline salts, occupying a tenth place out of 73 woods experimented upon.

Fir (*Pinus sylvestris*). — Of all the species this is the most valuable for its timber; it is produced in most parts of Europe, and its quality varies according to the soil on which it is grown: on a stiff cold earth, the wood has a red tinge, and acquires a solidity which it does not attain on sandy or light lands, where it becomes in colour nearly white. Sweden and Norway, as well as Prussia, Poland, and Russia, supply the English market from their extensive forests with both timber and deals cut out of this tree; the timber is floated on the Gotha to Gottenburgh, being divested of its bark, and on the Glomm to Christiana: but that most esteemed from the Baltic is the Riga, which is preferred for masts by the navy; the Russian timber is said to take so long a time in reaching Cornstadt, the port from whence it is exported, as to lose much of its quality.

In Scotland this species of fir, on favourable soils, attains considerable size, and forms most excellent timber; one tree at Dunmore contained 300 cube feet; and its durability, particularly the red, is equal to that of the oak: there are instances of its being found in the roof of a castle, after 300 years, as full of resin and as fresh as any newly imported from Memel.

The appearance of fir timber differs materially: in the best, the concentric rings are seldom so much as $\frac{1}{8}$ inch in thickness, whilst they increase in the inferior kinds; the colour is of a reddish yellow, and it has no large transverse septa: when spongy, and presenting a woolly texture, it is improper for the purposes of construction.

	lbs.	lbs.
A cubic foot of this tree in a green state weighs from	54	to 74
Ditto dry - - -	31	to 41

Pinus Strobus. — The white or Weymouth pine is brought into the English market from Canada or North America: its annular rings are not very distinct, nor is its durability remarkable, being subject to dry rot; a cubic foot when dry weighs 29 lbs.

Pinus Mitis, or yellow pine, called in England the New York, is very full of turpentine, and more durable and of greater strength than the white pine above mentioned: it does not attain so large a size, but is a more valuable timber.

Pinus Abies, or Norway Spruce, is another variety of white deal, and considerable quantities are annually imported from Christiana, which are highly esteemed for their quality: a cubic foot weighs 34 lbs. when dry.

Holly. — The veins of this wood are scarcely perceptible, but it is valuable for many purposes, to the joiner, cabinet-maker, engineer and turner, as well as to the wood-engraver: when dyed black it is a substitute for ebony.

	lbs.	oz.	
When perfectly dry it weighs - - -	47	7	per cube foot.

Hornbeam. — A hard, heavy, tenacious wood, very close-grained, is diminished much in drying, and consequently loses weight: the cogs of wheels are usually made of it, for which purpose it is well adapted.

	lbs.	
When green it weighs - - - -	64	per cubic foot.
half dry - - - - -	57	
quite dry - - - - -	51	

Laburnum is in use amongst turners: pulleys and blocks are made of it, being a hard and compact wood; it is capable of endurance when exposed to the weather, and for various purposes, is extremely valuable.

	lbs.	oz.
When perfectly dry a cube foot weighs - - -	52	11

Larch (*Larix*). — This valuable timber comes to perfection in a good soil in about 40 years: the colour of its wood is a yellowish white; on some soils, particularly if on an elevated situation, it is of a reddish brown and very hard, so much so that it is difficult to season, as it warps and twists in every direction; this wood not being so knotty as that of the fir, is excellent for all sorts of carpenter's work, being from its strength well adapted for girders and principal timbers. Scammozzi thinks it the most useful of all woods for the purposes of construction; it is not attacked by worms; he also mentions the enormous size of some of the trees growing in the Venetian Alps, many of which he employed in the public buildings at Venice. The Romans used this timber, and procured it from Rhetia and Switzerland, floating it down the Po, then by the Adriatic, the Ionian and Tyrrhenian Seas, and finally by the Tiber to the Capitol: no wood endures so long under water: in France and Switzerland it is much used for pipes to conduct water for the irrigation of the lands, particularly in Provence; by the Swiss it is universally preferred; they cover their houses with shingles made of it, and from its taking a high polish after planing it gives an agreeable finish to the interior: the closeness of its grain, and the strength of its fibres, enable it to resist twisting; it is not subject to crack, from which cause it was selected, according to Pliny, by the painters of old, as it was by Raphael in later times. The knots are never in a state of decay, and it is much

less liable to shrink than the other kinds of deal, nor will it split with the grain to any considerable length, from the crossing of its fibres.

Lignum Vitæ, is a hard wood much used by millwrights; its specific gravity is 1·333, and the weight of a cubic foot is 83·31 pounds avoirdupois.

Lime is a beautiful ornamental tree, and grows to a prodigious size, acquiring a diameter of 15 or 16 feet: the wood is of a pale yellow colour, close-grained, soft, light, and smooth in its texture, admirably adapted for the purposes of fine carving and cabinet-work.

Maple (*Acer Pseudo-platanus*) is found growing in mountain districts, and valuable for its lightness, and not being subject to warp or split it will take any colour and a fine polish.

	lbs.	oz.	
When green, it weighs	61	9	per cubic foot.
dry,	51	15	—

Sugar Maple, (*Acer saccharinum*). The bird's-eye maple, from the beauty of its grain and the shades of its spots, is much employed for veneering; by sawing the timber nearly parallel with the concentric rings, the effect of its marking or pencilling is much improved: in America wheelwrights employ it, after giving it a seasoning for three years, and when constantly under water it will not readily perish.

Mahogany (*Swietenia Mahogani*) is the produce of America and the West Indies, and it is principally imported from Honduras and Campeachy: that imported from the islands is called Spanish mahogany; the annular rings are not very distinct, it has no large septa, and warps less than most other woods: that brought from Honduras is the production of low marshy ground, and is coarse, soft, and spongy, whilst the most beautiful mottled and veined is grown upon high ground, and is often very valuable, being cut into veneers eight or ten to an inch: worms will not attack it when properly seasoned, but exposure to our climate soon destroys it; it is much used in parts of machinery, furniture, and portions of joiners' work, where ornament is studied. The weight of a cube foot is from 35 to 53 lbs.

Oak, (*Robur Quercus, or pendiculata*). — The common English Oak acquires considerable size, but does not grow so tall as some of the other species; its wood from its hardness is difficult to work, though preferred, where solidity is required: the Greeks call this species drys; the leaves have short footstalks, and the acorns long ones; the grain of the wood is fine, of a reddish tinge, free from knots, and will cleave easily into pales or lathes; where stiffness is an object, as in guiders or joists, it is very useful, as it will not bend readily.

	lbs.	oz.	
When green it weighs	76	13	per cube foot.
half dry	65	9	—
perfectly dry	52	13	—

Oak—(*Quercus sessiliflora*). — In this variety of oak, the wood is of a softer quality, and consequently yields more readily to the tools of the workman; the leaves are attached by long footstalks, and the acorns set close to the branches, differing in this particular from the specimen above described: the timber is subject to warp and split, but in consequence of its elastic qualities, it is highly prized for ship-building, its toughness and strength recommending it for that purpose; its hardness is sufficient for all ordinary purposes where oak is required. The grain of this variety bearing a strong resemblance to that of the chestnut, it is often mistaken for it, and it will last a long time, when preserved either entirely dry or under water.

	lbs.	oz.	
When green it weighs	80	5	per cube foot.
half dry	67	12	—
perfectly dry	51	10	—

Among the other varieties of the oak is the Etumodrys, which grows more lofty than the robur; the Esculus, or holm oak, mentioned by Vitruvius as having "its elements composed of earth, air, fire and water, in more equal proportions than others, is of great use in building, but damp soon destroys it; and its air and fire being driven off, it soon rots." The Quercus Ilex, or holm oak, is probably the Cerrus of Vitruvius; it produces acorns similar to that of the Esculus, which are also edible; the leaves continue during the winter, and the tree lives to a great age; its bark is very thick; the wood takes a fine polish; like other hard specimens it splits and warps in drying, though it possesses considerable flexibility; it weighs 70 lbs. the cube foot.

Oak (*Quercus alba*), or American oak, and the Quercus rubra of Canada, are of quick growth, but not so durable as the British oak: wainscot is obtained from the Riga oak, which is very clean and free from knots, and much in request by the joiner, forming good floors and wainscoting.

Olive.— This wood, when covered with mortar, endures a long time, and was much employed by the ancients to tie their walls together, as well as to form their roofs, when these were covered with stucco, and for all sorts of carpenters' work.

Plane (*Platanus orientalis*) is a native of the Levant, and its wood much resembles the beech; the trunk of the tree grows very lofty and straight before it throws out branches. Pliny mentions one at Lycia the circumference of which was 81 feet; in its cavity eighteen persons were entertained at dinner. The wood is applied to many useful purposes by the joiner and cabinet-maker.

Plane (*Planus occidentalis*) is produced in North America, and is of a more hardy quality than that just described: its diameter on the borders of the Ohio and Mississippi is sometimes as much as 12 feet; it will last a considerable time under water, and is used for the construction of quays, &c.; when dry it weighs from 40 to 46 lbs.

Poplar (*Populus*). — The different kinds are useful in building; one is especially preferred in Lombardy, which, when cut into planks, has considerable durability; Vitruvius says, where great strength is not required, it may be used, and certainly if maintained in a dry state will last a long time: when applied for flooring boards, two or three years' seasoning is required, as it loses much of its bulk in drying; it does not easily split by driving nails into it, and it has an advantage over many other timbers in not catching fire easily.

	lbs.	oz.	
When green it weighs	58	3	per cube foot.
in dry state	38	7	—

Populus tremula, (trembling poplar,) is another variety,

	lbs.	oz.	
weighing when green	54	6	per cube foot.
half dry	40	8	—
quite dry	34	1	—

Populus nigra, the black poplar; its wood is more soft and fibrous, splitting with more facility, and shrinking in its drying nearly one-sixth of its bulk; it is easy to work, does not splinter, and is useful to wheelwrights and turners.

	lbs.	oz.	
In a green state it weighs	60	9	per cube foot.
half dry	42	13	—
dry state	29	0	—

Populus fastigiata (*Lombardy Poplar*) is much used for the linings and fitting-up of store-rooms, as it is said mice will not attack it, and is well suited for the joiners' work of a cottage: the weight of a cube foot in a dry state is 24 lbs.

Sycamore, or Great Maple: when in a dry state the wood is durable, but the worm soon attacks it; it is susceptible of a polish, and will not easily warp.

When green a cube foot weighs	64 lbs.
half dry	56
dry	48

Losing a twelfth part of its bulk in drying.

Walnut (*Juglans regia*). — The wood is solid, compact, easy to work, will neither warp nor crack, has a beautiful vein, and is rightly esteemed one of the choicest of English woods. Hilly and poor calcareous soils produce the finest timber; when used in building it will bend under ordinary weights, but will not crack without giving due notice: rooms wainscoted with it have a good effect, and it was formerly much employed by cabinet-makers; screws of presses and gun-stocks are generally made of it.

	lbs.	oz.	
When green it weighs	58	8	per cube foot.
dried	46	8	—

Juglans alba grows to a large size; its wood is very tough and flexible.

Juglans nigra has a more beautiful vein, and takes a higher polish, and is esteemed superior to all other varieties for cabinet-work.

Willow (*Salix*): this wood is soft, smooth, and light, which occasioned it to be made into shields by the Romans; if kept from wet, it will last a long time in rafters or other light timbers.

	lbs.	oz.
Salix caprea, a cube foot when dry weighs	41	6
Salix alba	27	6

The first losing a twelfth, and the latter a sixth part of its bulk in drying.

In Scotland the red willow (*S. fragilis*) is used for building small vessels in consequence of its lightness, pliability, elasticity and toughness; the wood is of a salmon colour,

and before wheels were rung with iron, this sort of willow was employed for the fellies, enduring under friction and exposure a longer time than most other woods.

Felling Timber. — To the timber-grower the object aimed at should be that of obtaining the largest quantity of hard and durable wood, as free from sap as possible: no tree should be severed from its stool until it has arrived at a state of maturity, and previous to its being thrown down, the natural juices which pervade it should be discharged and allowed to run out, that the wood may be freed from what would bring about premature decay, and prevent its becoming dry and hard.

Barking the tree whilst in a growing state, and cutting through the sop or sap-wood, so as to allow the juices to be discharged, are practices of high antiquity. Vitruvius observes that both the density and the strength of timber are much improved by causing the tree to die standing: and most persons have agreed that barking the timber, previous to felling, greatly improved its quality. "When a tree has an incision made through the sap-wood at its trunk it soon dies, and no further change takes place; and the barking of trees, when in full growth and vigour, and letting them stand a twelvemonth after the operation, is admitted not only to improve the quality, but to increase the quantity, at the same time that it seasons the wood: time, however, is the best seasoner, and no artificial method can equal the natural process, which is that of getting rid of all juices in so regular a manner, that dissipating them does not too rapidly shrink and crack the timber. Trees may be suffered to stand too long before they are cut down; but this is not a usual fault, for often when they can measure to a load, which in half a century is sometimes the case, they are marked for felling, the heartwood not having either acquired its hardness or its full quantity."

Seasoning Timber. — Nothing more effectually contributes to this purpose than suffering it to lie for a time in fresh water; and our fir timber on its arrival is usually formed into floats on the Thames, where it remains for some time; thus the natural juices of the tree are removed by the water penetrating throughout its pores; this not containing any quality to produce fermentation, and being afterwards easily evaporated, tends to improve it for building purposes. Salt water, on the contrary, would require a considerable time to evaporate from the wood, in consequence of its deliquescence, and would render it unfit for use: when taken out of the water, it should be suffered to become thoroughly dry before it is carried to the pit to be sawn; and the usual method adopted is to block it up from the ground, and suffer a free circulation of air around it. When the tree is cut into scantlings, a further seasoning should be permitted by a free exposure to air, guarding against too violent an effect of wind or the sun's rays, and if it be cut into boards, they should be piled one on the other, with fillets or small pieces of wood between them, or laid in a triangular form, with their ends alternating, so as to permit the air to pass freely about them.

Gradual drying should always be resorted to, as it invariably produces the most durable timber, the object of seasoning being chiefly to drive off the water, and not to disturb any portion of the carbon, which would certainly be the consequence of elevating the temperature of the wood, or exposing it to great heat. Timber dried too quickly loses its toughness as well as its pliability; the outer pores become rapidly contracted, and do not permit the moisture from within to pass off freely.

Experiment has proved that oak, when seasoned properly, has lost nearly two-fifths of its weight, showing the necessity of allowing a sufficient time for the juices to be thoroughly driven off, which time must vary in proportion to the scantling of the timber; if cut into thin planks the operation of seasoning would be perfected in quicker time than that which would be necessary for the entire tree. All timber should be permitted to arrive at this dry state before it is cut into smaller scantlings or planks, great shrinking being the consequence of their suddenly drying by exposure to the air, which, by disturbing the fibres of the wood, affect its durability: to avoid this it was formerly the practice, after the planks were cut out by the sawyer, to prevent their exposure to the air, by laying them immediately in a running stream, and after some time to dry them very gradually, care being taken that the planks, when immersed, were removed from atmospheric influence; but, like steaming or boiling, this injured the strength of the wood, though it prevented its warping, and rendered it easier to work. The changes produced by these artificial processes undoubtedly injure the fabric of the wood; when a piece of thoroughly seasoned timber is immersed in water, and afterwards subjected to the heat of a stove, it will weigh less than previously; consequently a portion of its carbon must have passed off.

Where posts or piles are to be driven or plunged into the earth, it has been from the earliest time customary to char the surface to be placed underground: but to apply this practice to green timber is injurious, as it confines within, rather than expels these juices, which by fermenting cause its decay; it may be serviceable in destroying any fungi or worms that may attach themselves, or prevent their preying upon the fibres of the wood.

Decay of Timber, its Causes. — As woods were supposed to differ in the proportions of their ultimate elements, various experiments have been made upon them. Dr. Prout has shown satisfactorily that their composition is similar, and that they consist of equal weights

of carbon and water: moist woody fibre in a state of decay evolves one volume of carbonic acid for every volume of oxygen absorbed; woody fibre containing carbon and the elements of water, the result of the action of oxygen upon it is the same as if pure charcoal had combined with oxygen; the elements of water are not, however, contained in the woody fibre in the form of water, but in their separate states.

When wood in water, therefore, putrefies or rots, carbon and oxygen are separated from it in the form of carbonic acid, and hydrogen in the form of carburetted hydrogen; when this decay takes place in the air its hydrogen does not combine with carbon but with oxygen, for which it has a much greater affinity at common temperatures, and being converted into vegetable mould, and in a state to be acted upon, is taken up by the plants which grow within its influence, whilst the oxygen which it contained is gradually given out to the atmosphere as its decomposition is carried on.

This decomposition may proceed, whether the air has free access or is excluded from it; under water or in dry air timber will endure for ages without much apparent change, but when it has been immersed, if the air be admitted freely, the oxygen surrounding it is converted at once into carbonic acid, and the woody fibre is decomposed: 240 parts of dry oak sawdust would convert 10 cubic inches of oxygen into as many of carbonic acid, which contains 3 parts by weight of carbon, whilst the weight of the sawdust is diminished by 15 parts, and 12 parts by weight of water are separated from the wood.

The decay of wood bears a strong resemblance to the slow combustion of those bodies containing a quantity of hydrogen, which is oxidised at the expense of the oxygen of the air, while carbonic acid is produced from the elements of the wood: carbonic acid is not, however, formed at a common temperature.

Wood in a state of decay sets free two atoms of oxygen and one of carbon for every two equivalents of hydrogen oxidised; this decay is not effected in a short space of time at common temperatures, or when humidity is not present: when timber not in a perfectly dry state is in contact with any of the alkaline earths, its decay is accelerated, the presence of an alkali enabling it to absorb oxygen, which alone it has not the power to do, whilst an acid would produce a different effect and retard decay. In a loamy soil timber will endure some time, because it is kept from contact with air: but if this earth contain much water, then decay will be produced: in moist situations, where the soil is composed of sand and carbonate of lime, decay is very rapid, the alkaline lime assisting much to hasten it.

When woody fibre or sawdust is moistened with water and excluded from the air for any time carbonic acid gas is evolved in the same manner as when the air is admitted, and a putrefaction takes place, converting it into a rotten state; when exposed to a certain degree of moisture and a temperature not sufficiently high to evaporate the water, decomposition takes place suddenly, and as this increases, carbonic acid and hydrogen are given out. Sapwood is consequently more perishable than the heartwood, as it contains those juices which more readily ferment; hence it must be obvious that unless they are abstracted by seasoning, mischief arises from confining them in the wood, by covering the surface with paint or pitch, or even bedding their ends solidly in newly constructed walls; when timber is quite immersed in water, and kept so, it is by no means so liable to perish as when exposed to moisture only, aided by a slight degree of warmth.

The well-seasoned timber employed by the carpenters of the middle ages, in the old halls particularly, as well as in our churches and chapter-houses, needed neither paint nor dressing of any kind to preserve them; and in many instances they are found sound after four or five centuries. The weather-boarding of our English barns, which in many instances is of undressed elm timber, owes its duration to a hard external surface, which it acquires by time, and which resists almost the edge of a sharp tool, or the point of a nail, apparently a coating of silica, quite impervious to water, or even the action of moisture; this silica may be derived from the decomposition of the wheat straw with which the barns are usually thatched.

When the engineer or the carpenter selects timber for the purposes of construction due regard must be paid to its firmness, density, and strength, without which qualities no solid or durable works can be executed. The great weight with which timber is sometimes loaded, placed vertically or horizontally, shows at once the caution which should be used in its selection, and when it is exposed to the action of the air, the necessity of having it so seasoned and protected that it should not be subject to decay: when employed in the formation of centres to the arch of a bridge, durability for a time only is required, but in permanent roofs and floors it should be capable of resisting all efforts which may destroy its utility or strength; its warping and shrinking in edifices entirely formed of it lead sometimes to the greatest inconveniences, as the strength of a truss may be entirely destroyed by this cause.

The oak and the fir are the species most in use, and are the best for the purposes of construction: the first has the advantage of duration over the other, and will bear either to be exposed to the action of the air, the water, or to be buried in the earth; in water it will endure to a time unknown, and it has the advantages also of strength over all other timber.

The oak varies in its specific gravity according to the soil which produces it; its strength is in proportion to its density, and that timber is the most durable which has this quality in the highest degree: density is mainly owing to the length of time occupied in the production of the wood; that which grows fast, as it will do on light soils, is not so heavy, or so hard and compact, as that produced on cold soils, and of consequence slower growth.

From all the experiments made upon the strength of oak timber it has been found that this is in proportion to its weight and density, and invariably the heaviest is the strongest: in the trunk of a tree the most dense wood is found in the lower parts; this quality decreases in those branches and portions farther removed from the base. Trees which are suffered to complete their growth have their heartwood throughout of the same weight and strength, whilst those cut down prematurely are found to possess these requisites only in their centre wood, which is considerably harder than that formed by the outer concentric rings; it may be said to decrease in hardness in arithmetical proportion as it approaches the sap-wood.

When a tree, however, is suffered to stand too long, and its decay has commenced, the outer wood is in many instances the hardest: the specific gravity of the oak when cut down varies from 1000 to 1054, and its weight per cube foot from 70 to 74 lbs.; this weight by seasoning is reduced to 60 or 63 lbs., and it has been shown that the greatest degree of dryness that can be acquired is when it has lost about one-third of its original weight; but in this state it is not so durable, and more apt to break when exposed to a strain, or when a weight is imposed upon it. That preferred for carpentry is when only one-sixth of its weight has been lost, as a certain portion of sap is necessary for the fibres of the wood to preserve their union; in a perfectly dry state they have less adherence, lose their stiffness, and split and break more readily; oak seasoned so as to reduce it to the weight of about 60 lbs. per cube foot is the most preferable.

The fir in common use is imported generally from the ports which surround the Baltic Sea, or from the coast of Norway or Sweden, and the best deals come chiefly from Christiana or other ports of Sweden, Prussia, or Petersburgh. The lightness and stiffness of this timber render it preferable for girders and framing in general; it is less expensive to convert, and, although not quite so durable as oak, has the advantage of cheapness. The timber of the best quality has its annular rings much thinner than that of the inferior kinds; and when the saw is put in it does not cut so as to leave a rough or woolly surface, nor is it in the least of a spongy quality.

White deal is obtained from the spruce fir, the best from timber of 70 or 80 years' growth; in seasoning it will lose about one-seventieth part: deals are usually 3 inches in thickness, and 9 inches wide, and are sold by the hundred, which consists of 120; whatever may be their thickness they are reduced to a standard; one of $1\frac{1}{2}$ inches in thickness, 11 inches wide, and 12 feet long, contains 1 foot $4\frac{1}{2}$ inches cube.

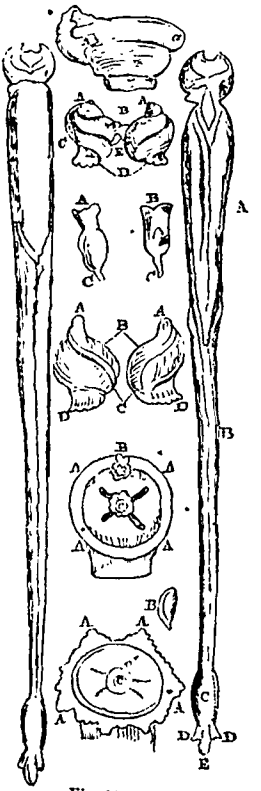


Fig. 2054.

The Teredo navalis is most destructive to timber used in the supports of a bridge or other purposes by the waterside: this *pile-worm*, as it is sometimes called, is particularly active in destroying timber in contact with the mud of rivers like the Thames; and wherever the water is brackish its ravages are certain. On the left of the figure the worm is represented on its belly, *about half its natural* size, and to the right on its back; A *a*, at the top of the figure, is the shell; A B C D E is the form of the hinge by which the shell is united; A C, B C, the two defences of the tail; A B D and A D C are its moving fibres; A A, the circular membrane covering the head; and the bottom figure, A A A A, is the same membrane turned back: this animal, so well described in the 41st volume of the Philosophical Transactions, No. 455., is very small when first exuded from the egg, but soon acquires a considerable size; its head is provided with a hard substance which resembles an auger, by which it penetrates the hardest wood; the fir and alder are the woods it most readily destroys.

The carpenter, before he commences any work, should thoroughly comprehend that important proposition in mechanics, which shows the composition and resolution of forces:

he should study well the nature of every strain, and its direction in the timber he is about to apply.

Suppose, for instance, an upright beam pushed in the direction of its length by a load at B, and abutting on the ends of two beams A C, A D, which are firmly supported at C and D; and as they cannot move, the pressures they sustain from the post B A are in the direction A C and A D: to ascertain what each of these timbers sustain, we must produce A E to B, taking A E from a scale of equal parts, to represent the number of tons or pounds by which B A is pressed: draw E F and E G parallel to A D and A C; then A F, measured on the same scale, will give the number of pounds by which A C is strained, and A G will give the strain A D.

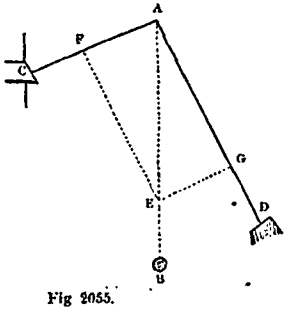


Fig 2055.

Where two pieces of timber, as A C and A D, are pressed or drawn down by a weight at B, the same rule will apply, and the nature of the strain produced must always be observed; in general, if the straining piece be within the angle formed by the pieces strained, the strains which they sustain are of the opposite kind to that which it exerts; if it be pushing, they are drawing, but if it be within the angle formed by their directions, the strains which they sustain are of the same kind; all the three are either drawing or pressing.

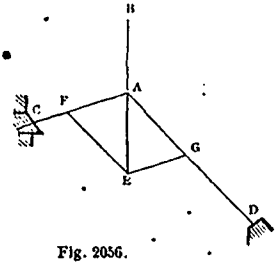


Fig. 2056.

Resistance of Timber to a transverse Strain. — The weight that will break a piece of timber must be ascertained before we can find the load that it will permanently bear; the stiffness of a beam is the proportion that exists between its deflection and its length, and the deflection, is what it sinks when loaded below a horizontal line: the deflection of beams of the same timber similarly loaded varies as the weight applied, and the cube of the length directly, and as the breadth and cube of the depth inversely, and this deflection should never be permitted to extend beyond $\frac{1}{360}$ part of the length, or $\frac{1}{10}$ part of an inch to the foot.

The lateral strength of a beam is less than its absolute longitudinal strength, either against extension or compression; timber will bear a considerable weight if suspended to it perpendicularly, or when pressing in the direction of its length, provided the timber is prevented from bending; and in using timber, a lateral strain should always be avoided, where a longitudinal one can be substituted.

Rectangular pieces of timber have their centres of gravity in the centre of their dimensions: a piece of timber 12 inches by 12 contains 144 square inches, and its centre of gravity will be 6 inches from each side; if the piece be broken by any load its fracture will terminate at the upper surface, or 6 inches above the centre of gravity. The area 144 multiplied by 6, gives 864 as the lateral strength, which may be applied in comparison with any other scantling of different dimensions on wood of the same quality: saw this piece of timber down the middle; the centre of gravity remains the same; if the sides are in the same vertical position, the area of the section of each is 72, and this multiplied by 6, the distance of the centre of gravity from the upper surface, makes half the product obtained before the timber was sawn; it is apparent, then, that, the depth remaining the same, the strength varies as the thickness: should the position of these latter timbers be reversed, that is, placed flat instead of on edge, the centre of gravity then is only 3 inches below the upper surface: the area of the end 72 being multiplied by 3, we obtain only 216 as the product, which is only half the strength which it had placed edgeways. The scantling which has the greatest strength is not all square, but that with the same area, which has its centre of gravity farthest from the top; a piece of timber 14 by 10 inches squares to 140 inches, and contains less than a piece 12 x 12, or 144 square inches: but the centre of gravity of the first is 7 inches from the top, and 140 multiplied by 7 produces 980, which exceeds 144 x 6 = 864. This is further illustrated by a plank 10 inches in depth and 1 inch in thickness; the sectional area, 10 inches, multiplied by 5, the distance in inches of the centre of gravity from the upper edge, the product is 50: the same piece placed flatwise must only be multiplied by $\frac{1}{2}$ inch; the product then is only 5, consequently the plank when placed on edge is ten times stronger than when placed flatwise.

A beam or piece of timber whose section is that of an equilateral triangle, when subjected to lateral pressure, is twice as strong, when resting on its broad base, as when placed on edge, the centre of gravity of this figure being at $\frac{1}{3}$ of its height measured from the base, or $\frac{2}{3}$ from its apex: the lateral strength of square beams is as the cubes of their breadth or depth; the lateral strength of any beams whose sections are similar are as the cubes of similar sides of the section. In cylindrical beams, the lateral strengths are as the

cubes of their diameters: in rectangular beams, the lateral strengths are to each other as the breadths and squares of the depths, the strength varying as the breadth multiplied into the square of the depth.

A piece of timber of the greatest strength that can be cut out from a round tree is obtained by dividing the diameter of the circle into three equal parts, raising perpendiculars upon it, and prolonging them till they cut the circumference; a rectangle uniting these points shows the form of the strongest beam that can be obtained. The comparative strength of beams, but not their actual strength, may be calculated by the foregoing rules: the value of actual strength must be converted into relative on account of the length and other dimensions being relative; thrice the length of a beam, is to its depth, as its absolute cohesion is to its relative strength, to which must be added the weight of the timber.

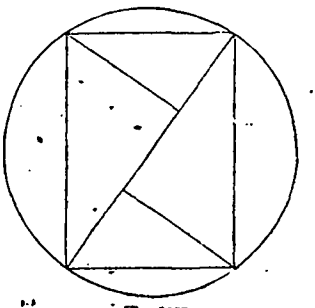


Fig. 2057.

The strains upon a beam fixed at one end in a wall and loaded at the other is four times greater than when the same weight is hung upon the middle of the same beam, and the latter supported at the two extremities: when a beam is fixed at both its extremities and loaded in the middle, its strength is to that when only supported at its two ends as 3 to 2: when a weight is uniformly distributed over a beam, its mechanical action to produce fracture is only one-half of what it is when collected in the middle.

Let l = the length in inches:
b = the breadth in inches:
d = the depth in inches:
W = the weight in pounds that would break it:
S = the weight requisite to break a piece of similar timber, whose length, breadth, and depth are each 1 inch: then,

$$\text{as } \frac{bd^2}{l} : 1 :: W : \frac{lW}{bd^2} = S,$$

which S will be a constant number of reference for computing the strength of any piece of timber of the same kind, under all variety of dimensions and modes of fixing and loading.

For a beam fixed at one end, and loaded at the other,

$$W = \frac{S b d^2}{l}$$

For a beam fixed at one end, and loaded uniformly throughout,

$$W = \frac{2 S b d^2}{l},$$

For a beam supported at each end, and loaded in the middle,

$$W = \frac{4 S b d^2}{l}$$

For a beam supported as above, and loaded uniformly,

$$W = \frac{8 S b d^2}{l}$$

For a beam fixed at one end, and loaded in the middle,

$$W = \frac{6 S b d^2}{l}$$

For a beam fixed as above, and loaded uniformly,

$$W = \frac{12 S b d^2}{l}$$

The value of S has been deduced from a variety of experiments, and in the following table is shown the experimental strength of different timbers, when exposed to a transverse strain.

Value of Cohesive Strength of a Rod an Inch Square.

Alder	1590	Fir, Norway	2376
Ash	2355	——, Scotch	1746
Acacia	1866	——, New England	1102
Beech	1556	——, Spruce	1395
Chestnut	1350	Larch	1896
Elm	1620	——, very young	966
Fir, Riga	1590	Mahogany, Spanish	1275
——, Memel	1635	——, Honduras	1911

Oak	1672	Poplar	981
——, Canadian	1766	Plane	1821
——, Dantzic	1457	Sycamore	1608
Pine, pitch	1632	Teak	2151
——, red	1341		

By the above table, to find the weight which will produce fracture, on a rectangular beam, supported at the two ends, when it is loaded in the centre, we must multiply the breadth by the square of the depth, and again by four times the constant value S: then this product, divided by the length in inches, will give the weight required. For example, it is required to know what weight would break a beam of English oak, 10 inches deep, 6 inches in breadth, and 20 feet long: $\frac{4 \times 6 \times 10^2 \times 1672}{240} = 16720$ lbs.

When the beam is fixed at one end, and loaded at the other, then the co-efficient 4 is omitted, and the weight is thus found,

$$\frac{6 \times 10^2 \times 1672}{240} = 4180 \text{ lbs.}$$

When the beam is uniformly loaded throughout, and supported at both ends,

$$\frac{4 \times 6 \times 10^2 \times 1672}{240} \times 2 = 33440 \text{ lbs.}$$

The application of the numbers given in the table to the preceding formula will afford the means of finding the weight that will produce fracture, and this weight diminished one-tenth, by cutting off one figure on the right hand, will give the weight in pounds that it ought to carry, and the timber should never be subjected to more; indeed it is never safe to put timber to the utmost of its efforts; a fourth of the breaking weight is in many cases considered sufficient.

To ascertain the weight or load any timber will bear when laid horizontally, the length and scantling being given, we must seek in the table for the breaking weight which corresponds to the length and scantling, and find the primitive horizontal strength of the timber in the second table. Thus, for a piece of oak 12·792 by 18·122, and 27·18 feet long, we find the breaking weight to be 85461; when fir is to be substituted, look into the second table for its primitive horizontal strength, which is 918. Then as 1000 : 918 :: 85461 : 78453, which expresses in pounds avoirdupois the weight that would break the piece of fir; diminish this weight one-tenth, and then 7845 lbs. is the weight it should be subjected to, or be made to carry.

Resistance to Compression in the Direction of its Length, or its Vertical Bearing Strength. — This power is as great as that which would tear it asunder, though, under some circumstances, it exerts a greater strength when used as a tie than as a strut; in the latter case, it is sometimes apt to bend, which it cannot do when pulled in the direction of its length. The resistance to compression is increased according to the position in which the strut or support is placed: when the weight applied begins to overpower it, the centre fibres swell, and the outer ones in consequence burst or lose their cohesion, and yield to the strain: resistance to such an effect depends on the lateral adhesion of the fibres, which may be resembled to a bundle of rods, which would not yield if bound round firmly together. Timber which has its fibre cross-grained offers still less resistance; therefore it is that a fir-post is capable of carrying three times as much as one of oak, although for a tie the oak is the strongest. The relative strength of timber against compression is as the cube of their diameters directly, and inversely as the square of its length; but the area of its section may be modified to produce greater strength; for a post in some places 9 by 4 is stronger than another 6 by 6; the stiffest post is that which has its sides in the proportion of 10 to 6.

Rondelet found the most simple method of ascertaining the absolute strength of oak, or its proportion for different lengths when lying between two points of support, was to multiply the area of the section by half the absolute strength, and to divide the product by the number of times its depth is contained in the length between the points of support, wherever beams are placed horizontally, and have a bearing at the two ends; those of equal depth diminish in strength, in proportion to the distance given between their supports: where the lengths are equal, their relative strengths are as their widths and squares of their depths.

The following tables, taken from Rondelet, and converted by Mr. Gwilt into English dimensions and weights, are of the greatest value in estimating the results of the various experiments made by Buffon upon timber. The first column gives the proportion that the depth has to the length; the second the length of each piece in English feet; the third the greatest strength of each piece in pounds avoirdupois.

TABLES showing the greatest Strength of Oak Timber, laid horizontally, in Pounds Avoirdupois.

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Breadth - 3·198 inches. Depth - 3·198 inches.		Breadth - 3·198 inches. Depth - 4·264 inches.		Breadth - 3·198 inches. Depth - 5·330 inches.		Breadth - 3·198 inches. Depth - 6·396 inches.			
6	1·599	12,245	2·132	16,326	2·664	20,418	3·198	24,489		
8	2·132	8,747	2·842	12,090	3·553	15,109	4·264	18,136		
10	2·664	7,163	3·553	9,547	4·441	11,934	5·330	14,321		
12	3·198	5,889	4·264	7,852	5·330	9,815	6·396	11,778		
14	3·730	4,980	4·974	6,642	6·218	8,303	7·462	9,963		
16	4·264	4,290	5·685	5,724	7·106	7,167	8·528	8,761		
18	4·796	3,771	6·396	5,027	7·994	6,283	9·594	7,540		
20	5·330	3,247	7·106	4,462	8·883	5,578	10·660	6,694		
22	5·862	3,000	7·817	4,000	9·771	5,010	11·726	6,001		
24	6·396	2,711	8·528	3,615	10·660	4,519	12·792	5,422		
26	6·928	2,447	9·238	3,289	11·548	4,111	13·858	4,934		
28	7·462	2,257	9·949	3,010	12·436	3,758	14·294	4,514		
30	7·994	2,076	10·660	2,767	13·324	3,459	15·990	4,150		
	Breadth - 4·264 inches. Depth - 4·264 inches.		Breadth - 4·264 inches. Depth - 5·330 inches.		Breadth - 4·264 inches. Depth - 6·396 inches.		Breadth - 4·264 inches. Depth - 7·462 inches.		Breadth - 4·264 inches. Depth - 8·528 inches.	
8	2·842	16,224	3·553	16,224	4·264	20,152	4·974	28,244	5·685	22,242
10	3·553	12,728	4·441	12,730	5·330	16,913	6·218	22,277	7·106	25,460
12	4·264	10,469	5·330	10,469	6·396	13,086	7·462	18,321	8·528	21,942
14	4·974	8,696	6·218	8,856	7·462	11,071	8·705	15,499	9·949	17,713
16	5·685	7,645	7·106	7,645	8·528	9,557	9·949	13,379	11·37	15,291
18	6·396	6,702	7·994	6,702	9·594	8,379	11·19	11,730	12·79	13,410
20	7·106	5,951	8·883	5,951	10·66	7,438	12·44	10,413	14·21	11,902
22	7·817	5,333	9·771	5,333	11·73	6,668	13·68	9,334	15·63	10,677
24	8·528	4,820	10·66	4,820	12·79	6,023	14·92	8,427	17·06	9,562
26	9·238	4,386	11·55	4,396	13·86	5,482	16·17	7,675	18·48	8,772
28	9·949	4,014	12·44	4,013	14·92	5,017	17·41	7,022	19·90	8,026
30	10·666	3,686	13·32	3,766	15·99	4,613	18·65	6,457	21·32	7,480

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Breadth, 5·330 in. Depth, 5·330 in.		Breadth, 5·330 in. Depth, 6·396 in.		Breadth, 5·330 in. Depth, 7·462 in.		Breadth, 5·330 in. Depth, 8·528 in.		Breadth, 5·330 in. Depth, 9·594 in.		Breadth, 5·330 in. Depth, 10·660 in.	
10	4·441	19,890	5·330	23,869	6·218	27,847	7·106	32,225	7·994	35,803	8·883	39,782
12	5·330	16,359	6·396	19,630	7·462	22,901	8·528	26,174	9·594	29,445	10·66	39,717
14	6·218	13,839	7·462	16,374	8·705	18,373	9·949	22,141	11·19	24,919	12·44	27,677
16	7·106	11,946	8·528	14,294	9·949	16,784	11·37	19,106	12·79	21,493	14·21	23,888
18	7·994	10,473	9·594	12,568	11·19	14,663	12·79	16,757	14·39	18,853	15·99	20,648
20	8·863	9,298	10·66	11,157	12·44	13,017	14·21	14,877	15·99	16,737	17·77	18,595
22	9·771	8,334	11·73	10,001	13·68	11,667	15·63	13,338	17·59	15,002	19·54	16,669
24	10·66	7,531	12·79	9,037	14·92	10,544	17·06	12,057	19·19	13,556	21·32	15,063
26	11·55	6,863	13·86	8,223	16·17	9,595	18·48	10,965	20·78	12,336	23·10	13,706
28	12·44	6,270	14·92	7,524	17·41	8,778	19·90	10,053	22·39	11,287	24·87	12,551
30	13·32	5,765	15·99	6,918	18·65	8,072	21·32	9,225	23·98	10,378	26·65	11,531
	Breadth, 6·396 in. Depth, 6·396 in.		Breadth, 6·396 in. Depth, 7·462 in.		Breadth, 6·396 in. Depth, 8·528 in.		Breadth, 6·396 in. Depth, 9·594 in.		Breadth, 6·396 in. Depth, 10·66 in.		Breadth, 6·396 in. Depth, 11·726 in.	
10	5·330	28,643	5·218	33,400	7·106	38,158	7·994	42,964	8·883	47,738	9·771	52,512
12	6·396	23,556	7·462	27,482	8·528	31,407	9·594	35,334	10·66	39,261	11·72	43,176
14	7·462	19,927	8·705	23,244	9·949	27,341	11·19	29,891	12·44	33,212	13·68	36,533
16	8·528	17,191	9·949	20,067	11·37	22,936	12·79	25,791	14·21	28,670	15·63	31,537
18	9·594	15,082	11·19	17,596	12·79	20,110	14·39	22,623	15·99	25,135	17·59	27,631
20	10·66	13,389	12·44	15,321	14·21	17,852	15·99	20,084	17·77	22,315	19·54	24,546
22	11·73	12,001	13·68	13,986	15·63	16,001	17·59	18,002	19·54	19,973	21·50	22,003
24	12·79	10,844	14·92	12,652	17·06	14,460	19·19	16,267	21·32	18,075	23·45	19,883
26	13·86	9,857	16·17	11,572	18·48	13,158	20·79	14,802	23·10	16,447	25·41	18,092
28	14·92	8,710	17·41	10,534	19·90	12,425	22·39	13,444	24·87	15,050	27·36	16,554
30	15·99	8,302	18·65	9,668	21·32	11,070	23·93	12,453	26·65	13,638	29·31	15,221

Length of each Piece in Feet.	Breaking Weight in Pounds.
Breadth, 6·396 in. Depth, 12·792 in.	
10·66	57,285
12·79	47,083
14·92	37,854
17·06	34,404
19·19	30,164
21·32	26,719
23·45	24,003
25·58	21,689
27·72	19,377
29·85	18,060
31·98	16,000

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Breadth, 7·462 in. Depth, 7·462 in.		Breadth, 7·462 in. Depth, 8·528 in.		Breadth, 7·462 in. Depth, 9·594 in.		Breadth, 7·462 in. Depth, 10·66 in.		Breadth, 7·462 in. Depth, 11·726 in.		Breadth, 7·462 in. Depth, 12·792 in.		Breadth, 7·462 in. Depth, 13·858 in.	
10	6·218	35,746	7·106	44,577	7·994	50,125	8·983	55,738	9·771	60,264	10·66	66,832	12·61	72,403
12	7·462	31,911	8·528	36,643	9·594	41,221	10·66	45,804	11·73	49,384	12·79	55,964	13·86	59,546
14	8·705	27,128	9·949	29,806	11·19	35,644	12·44	38,757	13·68	42,622	14·92	46,497	16·17	50,371
16	9·949	23,413	11·37	26,746	12·79	30,103	14·21	33,449	15·63	36,792	17·06	40,138	18·48	43,483
18	11·19	20,530	12·79	24,060	14·39	26,394	15·99	29,226	17·59	31,808	19·19	34,992	19·72	38,124
20	12·44	18,224	14·21	21,838	15·99	23,432	17·77	26,142	19·54	28,637	21·32	31,241		
22	13·68	16,335	15·63	18,667	17·59	21,003	19·54	23,325	21·50	24,719	23·45	28,003		
24	14·92	14,761	17·06	16,870	19·19	18,979	21·32	21,807	23·45	23,196	25·58	25,305		
26	16·17	13,436	18·48	15,418	20·79	17,270	23·10	19,139	25·40	21,307	27·72	23,068		
28	17·41	12,637	19·90	14,046	22·39	15,802	24·97	17,557	27·36	18,928	29·85	21,070		
30	18·65	10,940	21·32	12,915	23·98	14,530	26·65	16,144	29·31	17,758	31·98	18,373		
	Breadth, 8·528 in. Depth, 8·528 in.		Breadth, 8·528 in. Depth, 9·594 in.		Breadth, 8·528 in. Depth, 10·66 in.		Breadth, 8·528 in. Depth, 11·726 in.		Breadth, 8·528 in. Depth, 12·792 in.		Breadth, 8·528 in. Depth, 13·858 in.		Breadth, 8·528 in. Depth, 14·924 in.	
10	7·106	50,921	7·944	57,285	8·883	62,651	9·771	69,975	10·66	76,381	11·55	82,746	12·44	89,111
12	8·528	41,878	9·594	47,093	10·66	52,348	11·73	57,582	12·79	62,817	13·86	68,052	14·92	73,279
14	9·949	35,426	11·19	39,854	12·44	44,283	13·67	48,711	14·92	53,139	16·17	57,576	17·41	61,996
16	11·37	30,581	12·79	34,403	14·21	38,227	15·63	42,049	17·06	45,872	18·48	49,627	19·90	53,517
18	12·79	26,812	14·39	30,170	15·99	33,516	17·59	36,668	19·19	40,219	20·79	43,628	22·39	46,923
20	14·21	23,803	15·99	26,773	17·77	29,754	19·54	32,729	21·32	35,715				
22	15·63	21,342	17·59	24,003	19·54	26,669	21·50	29,337	23·45	32,004				
24	17·06	19,280	19·19	21,690	21·32	24,100	23·45	26,017	25·58	28,920				
26	18·48	17,345	21·95	19,737	23·10	21,930	25·40	24,124	27·72	26,356				
28	19·90	16,051	23·45	17,960	24·87	20,066	27·36	22,073	29·85	24,851				
30	21·32	14,760	25·05	16,605	26·65	18,444	30·20	20,295	31·98	22·149				

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Breadth, 9·594 inches. Depth, 9·594 inches.		Breadth, 9·594 inches. Depth, 10·66 inches.		Breadth, 9·594 inches. Depth, 11·726 inches.		Breadth, 9·594 inches. Depth, 12·792 inches.		Breadth, 9·594 inches. Depth, 13·858 inches.		Breadth, 9·594 inches. Depth, 14·924 inches.	
10	7·994	64,447	8·983	71,607	9·771	78,848	10·66	85,929	11·55	93,089	12·44	100,250
12	9·594	52,992	10·66	58,891	11·73	64,780	12·79	70,670	13·86	76,458	14·92	82,447
14	11·19	45,402	12·44	49,818	13·68	54,800	14·92	59,782	16·17	64,763	17·41	69,745
16	12·79	38,704	14·21	43,010	15·63	47,305	17·06	51,406	18·48	55,906	19·90	60,207
18	14·39	33,935	15·99	37,705	17·59	41,476	19·19	45,247	20·79	49,117	22·39	52,771
20	15·99	30,125	17·77	33,473	19·59	36,820	21·32	40,167				
22	17·59	27,003	19·54	30,003	21·50	33,004	23·45	36,004				
24	19·19	24,401	21·32	27,112	23·45	29,825	25·58	32,535				
26	20·79	22,205	23·10	24,671	25·40	27,138	27·72	29,606				
28	22·39	20,317	24·87	22,574	27·36	24,830	29·85	27,090				
30	23·98	18,681	26·65	20,756	29·21	22,832	31·98	24,908				
	Breadth, 10·66 inches. Depth, 10·66 inches.		Breadth, 10·66 inches. Depth, 11·726 inches.		Breadth, 10·66 inches. Depth, 12·792 inches.		Breadth, 10·66 inches. Depth, 13·858 inches.		Breadth, 10·66 inches. Depth, 14·924 inches.		Breadth, 10·66 inches. Depth, 15·990 inches.	
10	8·883	79,564	9·771	87,520	10·66	95,476	11·55	103,633	12·44	111,389	13·32	119,345
12	10·66	65,435	11·73	71,978	12·79	78,521	13·86	85,065	14·92	91,609	15·99	98,152
14	12·44	55,453	13·67	60,889	14·92	64,424	16·17	72,037	17·41	77,495	18·65	83,030
16	14·21	47,783	15·63	52,548	17·06	57,340	18·48	62,118	19·90	66,896	21·32	71,675
18	15·99	41,895	17·59	45,985	19·19	50,274	20·79	54,463	22·39	58,653	23·98	62,841
20	17·77	37,192	19·54	40,911	21·32	44,631						
22	19·54	33,337	21·50	36,671	23·45	40,005						
24	21·32	30,125	23·45	33,138	25·58	36,151						
26	23·10	27,412	25·40	30,155	27·72	32,896						
28	24·87	24,083	27·36	27,491	29·85	30,100						
30	26·65	23,061	29·21	25,369	31·98	27,676						

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Inches. Breadth, 11·726 Depth, 11·726		Inches. Breadth, 11·726 Depth, 12·792		Inches. Breadth, 11·726 Depth, 13·858		Inches. Breadth, 11·726 Depth, 14·924		Inches. Breadth, 11·726 Depth, 15·99		Inches. Breadth, 11·726 Depth, 17·056		Inches. Breadth, 11·726 Depth, 18·122	
10	9·771	96,272	10·66	105,023	11·55	113,776	12·44	122,528	13·32	131,280	14·21	148,784	15·10	157,537
12	11·73	79,174	12·79	86,374	13·86	93,572	14·92	100,769	15·99	107,968	17·06	122,362	18·12	129,561
14	13·67	66,978	14·92	73,067	16·17	79,155	17·41	85,244	18·65	91,333	19·90	103,511	21·14	109,600
16	15·63	57,818	17·06	63,074	18·48	68,328	19·90	73,576	21·32	78,842	22·74	89,355	24·16	94,611
18	17·59	51,493	19·19	55,301	20·79	60,910	22·39	64.518	23·98	69 126	25·58	78,344	27·18	82,350
20	19·54	45,002	21·32	49,093										
22	21·50	40,338	23·45	44,006										
24	23·45	36,407	25·58	38,765										
26	25·40	33,087	27·72	36,185										
28	27·36	30,350	29·85	33,109										
30	29·21	27,906	31·98	30,443										

Length of each Piece in Feet.	Breaking Weight in Pounds.
Inches. Breadth, 11·726 Depth, 19·188	
16·88	181,405
20·25	149,191
23·63	126,207
27·00	108,946
29·38	95,521

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Inches. Breadth, 12·792 Depth, 12·792		Inches. Breadth, 12·792 Depth, 13·858		Inches. Breadth, 12·792 Depth, 14·924		Inches. Breadth, 12·792 Depth, 15·99		Inches. Breadth, 12·792 Depth, 17·056		Inches. Breadth, 12·792 Depth, 18·122		Inches. Breadth, 12·792 Depth, 19·188	
10	10·66	115,572	11·55	124,119	12·44	133,667	13·32	143,214	14·21	152,762	15·10	162,310	15·99	171,857
12	12·79	89,826	13·86	102,078	14·92	110,930	15·99	117,783	17·06	125,634	18·12	123,487	19·19	141,340
14	14·92	79,709	16·17	86,351	17·41	92,994	18·65	99,636	19·90	106,279	21·14	112,921	22·37	119,565
16	17·06	68,708	18·48	74,542	19·90	80,275	21·32	86,010	22·74	91,744	24·16	97,479	25·58	103,212
18	19·19	60,329	20·79	65,356	22·39	70,384	23·98	75,411	25·58	76,238	27·18	85,461	28·78	88,894
20	21·32	53,557												
22	23·45	48,006												
24	25·58	43,380												
26	27·72	39,475												
28	28·85	36,119												
30	31·98	33,211												

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Breadth, 13·858 in. Depth, 13·858 in.		Breadth, 13·858 in. Depth, 14·924 in.		Breadth, 13·858 in. Depth, 15·99 in.		Breadth, 13·858 in. Depth, 17·056 in.		Breadth, 13·858 in. Depth, 18·122 in.		Breadth, 13·858 in. Depth, 19·188 in.	
10	11·55	134,463	12·44	144,806	13·32	154,825	14·21	164,426	15·10	175,836	15·99	141,179
12	13·86	110,584	14·92	119,092	15·99	127,598	17·06	136,153	18·12	144,611	19·19	133,115
14	16·17	93,547	17·41	100,813	18·68	107,939	19·90	114,364	21·14	121,332	22·37	129,528
16	18·48	80,754	19·90	86,966	21·32	93,177	22·74	99,396	24·16	105,601	25·58	111,813
18	20·79	70,802	22·39	76,249	23·98	81,755	25·58	91,941	27·18	92,588	28·78	98,935
	Breadth, 13·858 in. Depth, 20·254 in.		Breadth, 13·858 in. Depth, 21·326 in.		Breadth, 13·858 in. Depth, 22·326 in.							
10	16·88	196,522	17·77	205,531	18·65	217,210						
12	20·25	161,624	21·32	170,130	22·38	178,637						
14	23·63	136,724	24·87	144,920	26·12	151,115						
16	27·00	118,026	28·43	124,237	29·85	130,049						
18	29·38	103,481	31·98	108,951	33·58	114,374						
	Breadth, 14·924 in. Depth, 14·924 in.		Breadth, 14·924 in. Depth, 15·990 in.		Breadth, 14·924 in. Depth, 17·056 in.		Breadth, 14·924 in. Depth, 18·122 in.		Breadth, 14·924 in. Depth, 19·188 in.		Breadth, 14·924 in. Depth, 20·254 in.	
10	12·44	155,944	13·32	167,083	14·21	178,223	15·10	189,362	15·99	200,501	16·88	212,547
12	14·92	128,092	15·99	137,213	17·06	146,674	18·12	155,735	19·19	164,895	20·25	174,057
14	17·41	108,493	18·65	116,242	19·90	123,993	21·14	131,741	22·37	139,492	23·63	147,331
16	19·90	93,655	21·32	100,354	22·74	107,054	24·16	113,764	25·58	120,415	27·00	127,104
18	22·39	82,114	23·98	87,980	25·58	93,845	27·18	99,711	28·78	105,575	29·38	111,441
	Breadth, 14·924 in. Depth, 21·326 in.		Breadth, 14·924 in. Depth, 22·386 in.		Breadth, 14·924 in. Depth, 23·452 in.							
10	17·77	212,776	18·65	233,917	19·54	246,136						
12	21·32	173,218	22·38	192,378	23·45	201,540						
14	24·87	150,991	26·12	162,737	27·36	170,490						
16	28·43	133,733	29·85	140,483	31·27	147,173						
18	31·98	117,306	33·58	112,372	35·18	129,037						

Proportion of Depth to Length.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.	Length of each Piece in Feet.	Breaking Weight in Pounds.
	Breadth, 15·99 in. Depth, 15·99 in.		Breadth, 15·99 in. Depth, 17·056 in.		Breadth, 15·99 in. Depth, 18·122 in.		Breadth, 15·99 in. Depth, 19·188 in.		Breadth, 15·99 in. Depth, 20·254 in.		Breadth, 15·99 in. Depth, 21·326 in.		Breadth, 15·99 in. Depth, 22·386 in.		Breadth, 15·99 in. Depth, 23·452 in.		Breadth, 15·99 in. Depth, 24·518 in.	
10	13·32	179,079	14·21	190,953	15·10	202,888	15·99	214,823	16·88	226,757	17·77	238,692	18·65	250,626	19·54	262,561	20·43	274,495
12	15·99	147,229	17·06	160,244	18·12	166,859	19·19	176,584	20·25	186,490	21·32	196,365	22·38	206,127	23·45	215,935	24·52	225,750
14	18·65	124,547	19·90	132,849	21·14	141,153	22·37	149,456	23·63	157,759	24·87	166,062	26·12	174,365	27·36	182,668	28·60	190,761
16	21·32	107,513	22·74	114,680	24·16	121,848	25·58	129,015	27·00	136,183	28·43	143,350	29·85	150,517	31·27	157,685	32·69	164,852
18	23·98	94,164	25·58	100,548	27·18	106,832	28·78	113,118	29·38	119,401	31·98	125,686	33·68	131,770	35·18	138,254	36·78	144,638
	Breadth, 17·056 in. Depth, 17·056 in.		Breadth, 17·056 in. Depth, 18·122 in.		Breadth, 17·056 in. Depth, 19·188 in.		Breadth, 17·056 in. Depth, 20·254 in.		Breadth, 17·056 in. Depth, 21·326 in.		Breadth, 17·056 in. Depth, 22·386 in.		Breadth, 17·056 in. Depth, 23·452 in.		Breadth, 17·056 in. Depth, 24·518 in.		Breadth, 17·056 in. Depth, 25·584 in.	
10	14·21	203,634	15·10	216,412	15·99	229,144	16·88	241,875	17·77	254,605	18·65	267,334	19·54	280,064	21·32	292,795	21·32	305,525
12	17·06	167,513	18·12	177,983	19·19	188,456	20·25	197,322	21·32	209,391	22·38	219,861	23·45	230,330	25·58	240,800	25·58	251,360
14	19·90	141,706	21·14	150,563	22·37	158,439	23·63	168,276	24·87	177,132	26·12	184,989	27·36	190,846	29·85	203,702	29·85	212,559
16	22·74	122,967	24·16	129,970	25·58	137,617	27·00	145,261	28·43	152,807	29·85	160,552	31·27	168,772	34·11	175,842	34·11	183,421
18	25·58	107,251	27·18	113,954	28·78	120,659	29·38	127,341	31·98	134,112	33·68	140,768	35·18	147,471	38·37	154,174	38·37	160,277
	Breadth, 18·122 in. Depth, 18·122 in.		Breadth, 18·122 in. Depth, 19·188 in.		Breadth, 18·122 in. Depth, 20·254 in.		Breadth, 18·122 in. Depth, 21·326 in		Breadth, 18·122 in. Depth, 22·386 in.		Breadth, 18·122 in. Depth, 23·452 in.		Breadth, 18·122 in. Depth, 24·518 in.		Breadth, 18·122 in. Depth, 25·584 in.			
10	15·10	229,907	15·99	243,465	16·88	257,091	17·77	270,317	18·65	284,043	19·54	297,569	20·43	310,771	21·32	324,621		
12	18·12	187,107	19·19	200,131	20·25	211,356	21·32	222,479	22·38	233,603	23·45	244,727	24·52	255,851	25·58	256,975		
14	21·14	169,973	22·37	169,383	23·63	178,793	24·87	188,203	26·12	197,611	27·36	207,023	28·60	216,434	29·85	225,844		
16	24·16	142,094	25·58	146,217	27·10	154,340	28·43	162,463	29·85	170,275	31·27	188,710	32·69	186,833	34·11	194·956		
18	27·18	121,077	28·78	128,199	29·38	135,261	31·98	142,443	33·58	149,266	35·18	156,688	36·78	163,810	38·37	170·933		
	Breadth, 19·188 in. Depth, 19·188 in.		Breadth, 19·188 in. Depth, 20·254 in.		Breadth, 19·188 in. Depth, 21·326 in.		Breadth, 19·188 in. Depth, 22·386 in.		Breadth, 19·188 in. Depth, 23·452 in.		Breadth, 19·188 in. Depth, 24·518 in.		Breadth, 19·188 in. Depth, 25·584 in.		Breadth, 19·188 in. Depth, 26·65 in.			
10	15·99	257,787	16·88	272,108	17·77	286,430	18·65	300,763	19·54	315,073	20·43	329,395	21·32	343,716	22·21	258,037		
12	19·19	212,107	20·25	223,788	21·32	235,565	22·38	247,344	23·45	259,122	24·52	270,901	25·58	286,679	26·65	294,458		
14	22·37	179,347	23·63	189,310	24·87	196,074	26·12	209,238	27·36	219,101	28·60	229,165	29·85	140,130	31·09	249,092		
16	25·58	150,818	27·00	163,419	28·43	171,010	29·85	180,261	31·27	189,222	32·69	197,824	34·11	207,092	35·53	216,026		
18	28·78	135,741	29·38	143,281	31·98	150,823	33·58	158,364	35·18	165,905	36·78	173,446	38·37	180,987	39·97	188,529		
	Breadth, 20·254 in. Depth, 20·254 in.		Breadth, 20·254 in. Depth, 21·320 in.															
10	16·88	287,226	17·77	292,343														
12	20·25	236,220	21·32	248,653														
14	23·63	199,827	24·87	200·345														
16	27·10	172,498	28·43	181·577														
18	29·38	151,242	31·98	159,202														

In the foregoing tables the primitive horizontal strength of oak is considered as 1000, its vertical strength at 807, and its cohesive or absolute strength at 1821: for its application to the other species of timber the following table has been calculated: —

	Primitive or. Horizontal Strength.	Primitive Vertical Strength.	Absolute Strength.
Apricot	1096	1255	2040
Acacia, yellow	780	1228	1560
Arbutus	857	1062	1620
Alder	644	780	2080
Ash	1072	1112	1800
Apple	976	903	1187
Aspen	624	717	1293
Birch	853	861	1980
Box	1160	1444	2324
Beech	1032	986	2480
Cedar	627	720	1740
Cherry	961	986	1912
Chestnut	957	950	1944
———, horse	931	689	1231
Citron	1192	871	1460
Cypress	682	869	1880
Ebony	1155	1062	2321
Elder	1072	789	1500
Elm	1077	1075	1980
Fir	918	851	1250
Lemon	1087	858	1400
Larch	843	902	1460
Lignum vitæ	707	741	1113
Lime	750	717	1407
Maple, foreign	1094	843	2094
Mulberry	981	1031	1050
Oak	1000	807	1821
Orange	1180	843	2340
Pine tree	882	804	1041
Plane	728	830	1916
——, Oriental	776	874	931
——, Occidental	853	941	1031
Poplar	586	680	940
Plum	950	843	1770
Pear	850	816	1680
Sycamore	900	968	1564
Service	965	981	1642
Tulip tree	563	682	981
Walnut	900	733	1120
———, American	864	701	1020
Yew	1037	1375	2287

This is deduced from pieces 19·188 lines English square.

When a piece of timber is put in an upright position, it seems at first that it will carry the same weight, whatever may be its length; but experience shows us that when a post is more than seven or eight times the width of its base in height, it bends under the weight, previous to crushing or giving way. When a post is 100 times its diameter, it is incapable of maintaining an upright position, and then we find its strength diminishes in relation to the height: to crush a piece of oak which is too short to bend, it requires 49·72 pounds avoirdupois for every $\frac{888}{1000}$ area of an inch at its base, and for fir timber 56·16 pounds.

Rondelet used cubes of oak and fir in the experiments he made, and found they diminished in height by compression previous to disuniting, the first more than a third, the latter a half: when either of these timbers are of a length to bend under the weight imposed upon them, they immediately have their strength diminished, and he found the mean strength of oak to be 47·52 pounds avoirdupois for a cube of $\frac{888}{1000}$ of an inch, which is reduced to 2·16 pounds, when the height is as much as 72 times the width of the base: for a cube whose height was 1, the strength was taken as 1; for a post equal to 12 times its base, the strength was five-sixths; for 24 times, a half only; for 36 times, a third;

48 times, a sixth; 60 times, a twelfth; and at 72 times the height of its base, its strength is only a 24th part. It results from the above experiments that we ought never to make a post in height more than ten times its diameter or width at the base; and in calculating its strength, at the rate of 10·80 pounds for every 1·066 line superficial of base, which is not a quarter of the weight that would crush it, we find that a post whose sides are 1·066 feet, and containing 22104·576 lines English, would sustain a weight of 238729 pounds avoirdupois, or 106 tons. When a post is made in height equal to ten times its width of base, it should never have in practice a weight of more than 5 pounds per 1·066 line imposed upon it: and when the height is 15 times the base, 4 pounds; and when 20 times, not more than 3 pounds for the same proportion: all posts should have their bases extended, or their area made proportionate to the weight they have to sustain: they ought also to have a stability given them, in reference to their situation and isolation; this stability is in proportion to the base, the diameter of which, as compared with the height, may vary as 7 to 10.

For Timbers placed vertically, as Posts, &c.— To find the vertical strength of an oak post 9·594 inches square and 9·594 feet high, seek in the preceding table for the primitive vertical strength of oak, which is 807 for 19·188 lines superficial of base; but as this strength should diminish in a ratio of the number of times that the width of the base is contained in the width of the post, which in the present case is 12, only $\frac{8}{12}$ of 807 must be taken, or 672½. This post, which is 9·594 inches, or 115·128 lines square, has an area of 13254·756 square lines, which being divided by 19·188 will give 692·34; and for the greatest weight it can bear before breaking, 692·34 × 672·5 = 465,000 lbs., and this divided by 10 gives 46,500 pounds as the weight the post may be loaded with: when the post is of fir, the primitive vertical strength of which is as 851 to 807, to have its greatest strength, it is only necessary to make the proportions, as 807 : 465000 :: 851 : 490980, which divided by 10 gives 49,098 pounds as the utmost weight it should be loaded with.

To find the absolute or cohesive Strength.— This strength by which timber resists when drawn at the two ends is ascertained by multiplying the area of the section, reduced to lines, by 1821 for oak, which is its tabular number, and dividing the product by 19·188, and the quotient will indicate the greatest weight that it ought to bear.

For oak, 9·594 inches square, $\frac{13254·75 \times 1821}{19·188} = 1{,}260{,}700$, which divided by 10 gives 126,070 pounds for the greatest weight it should be subjected to.

We find by the table that beech has the greatest absolute strength, so that a piece of timber of the same dimensions as the preceding would have a strength by $\frac{13254·75 \times 12480}{19·188} = 1{,}363{,}850$, which will give 136,385, as the greatest weight to which it ought to be subject.

To find the Strength of Timber when in an inclined Position.— If it be supposed that a piece of vertical timber, as A B, be inclined on its base, experience proves that its strength to support a vertical effort diminishes in proportion to its inclination, so that if from its upper extremity a vertical D*f* be lowered, and from the points of the base B a horizontal line B C be drawn, the strength of the piece will be less in proportion as B*f* is larger: whence it results that the strength of a piece of vertical timber is to that of an inclined piece of the same scantling, as the length A B is to B*f*, or as the radius to the size of the inclination of the timber.

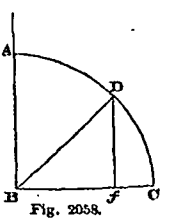


Fig. 2058.

Secondly, the vertical pieces have the greater power to support a weight, and the horizontal the less; the first of these results gives an easy method by means of the preceding table, to find the strength of a piece of timber, the length and inclination of which are known: for example; a piece of oak 9·594 feet long, inclined 4·692 feet, its dimensions being 8·528 by 9·594 inches, whose area therefore is 11781·74 lines; this must be divided by the tabular number, 19·188, and the quotient will be 614.

In the preceding table 807 is the primitive vertical strength of oak for 19·188 lines superficial of section; but as the length of this piece is more than twelve times the width of the base, we must only take $\frac{8}{12}$ of 807, viz. 672½, which multiplied by 614 gives 412915. Then 9·594 : 4·692 :: 412915 : 843400; this divided by 10 gives 84,340 for the utmost load to which the inclined piece should be loaded.

Joints and Joining Timbers.— As timber cannot always be obtained of sufficient length for tie-beams or bridges, it is necessary to show the method usually employed to unite two or more pieces together by their ends, which is called scarfing, and is differently performed by carpenters: the most common means is lapping or halving, or as it is sometimes called ship-lapping. This is nothing more than cutting away a part of the thickness of one piece, and an equal quan-

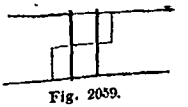


Fig. 2059.

tity of the other, which is to be joined to it, so as to suffer the diminished end of one piece to overlap that of the other, and then uniting them by nails or wooden pins, which are called tree-nails. This method is applied to plates, bond timbers and others, where there is not much longitudinal compression or extension: where this kind of effect is to be provided for, the upper as well as the lower timbers should be cut and let into each other; the under piece having a tenon formed at its extreme end, with a corresponding cutting to receive it in the upper piece; that these tenons may be enabled to pass each other, it is necessary to cut away a part of the timbers in the middle of the length of the joint, equal to the length of the two tenons, so as to form a square hole, through the middle of the timbers to be joined together, and this is afterwards closed up by driving an oak key into it; this also helps to drive the tenons to their respective mortises, and prevents the timbers from being pulled asunder: the thickness of the key, in order that it may not be compressed, should be equal to a third of that of the piece into which it is inserted: another principle is here shown, which is more simple, the joint being cut obliquely; to make these two pieces stiff, the ends of both should be cut in an angular form. To strengthen these scarfs, iron straps and screw-bolts are added, but no joining can be made so strong as the timber itself.

In making joints, it must be remembered that all timber is liable to shrink when dry, and when wet to expand; on this account dovetail joints should be avoided as much as possible, as they are liable to draw out, and all joints should be made with reference to their contraction and expansion, which sometimes tends to split off portions of the framing: where iron bolts or straps are introduced care must be taken that their effect is not lost by the changes that the timber undergoes; the areas of the former should never be less than two-tenths of the area of the section of the beam; it must also be recollected in making a joint, that when force is applied to any portion, the fibres of the timber will slide upon each other.

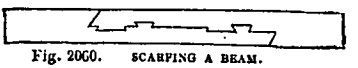


Fig. 2060. SCARFING A BEAM.

Fishing a Beam is merely placing a piece of the same scantling to one side of the timber to be united, and bolting them or hooping them together: separate pieces of timber are united either by scarfing, notching, cogging, pinning, wedging, tenoning, &c.

Scarfing consists in cutting away equally from the ends, but on the opposite sides, of two pieces of timber for the purpose of connecting them lengthwise: the usual method of scarfing bond and wall plates is by cutting about ⅔ through each piece on the upper face of the one, and the under face of the other, about 6 or 8 inches from the end transversely, making what is termed a *kerf*; and longitudinally from the end, from ⅔ down, on the same side, so that the pieces lap together like a half dovetail.

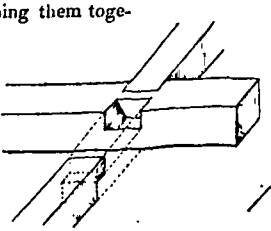


Fig. 2061.

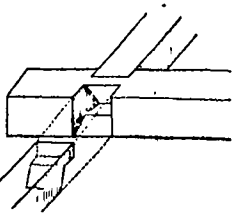


Fig. 2062.

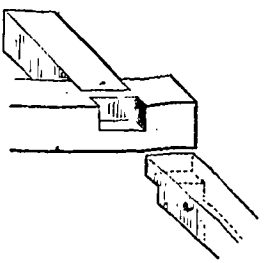


Fig. 2063.

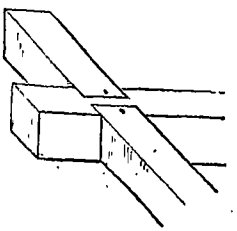


Fig. 2064.

Notching is either square or dovetailed, and is made use of for connecting the ends of wall plates and bond timbers at the angles, in letting joists down on girders, binders, purlins or principal rafters.

Cogging or Cocking is a species of notch extending on one side, and having a narrow cog alone in the bearing piece, flush with its upper face; it is principally made use of in tailing joists on wall plates.

Pinning consists in inserting cylindrical pieces of wood or iron through a tenon.

Wedging is the insertion of triangular prisms, whose converging sides are under an extremely acute angle, into or by the end of a tenon, to make it fill the mortise so completely as to prevent its being withdrawn.

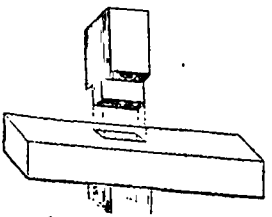


Fig. 2065.

Tenon and Mortaise or Mortise of the most simple kind, in which the two timbers united are at right angles with each other; the tenon is on that which appears horizontal, whilst the mortise is cut in the upright timber; the tenon is left one-third of the thickness of the timber, as shown in the upper part of the figure.

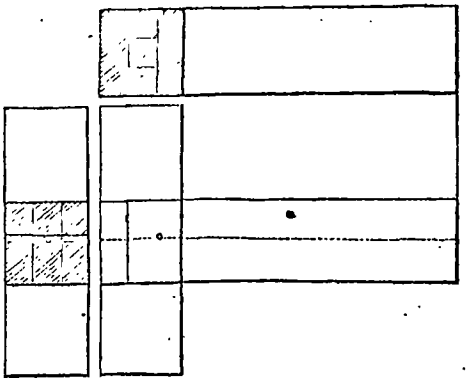


Fig. 2066. TENONS AND MORTISES.

The greatest strain upon the fibres of a girder is at the upper and lower parts, decreasing gradually towards the middle of the depth, which is the best situation to make the mortise. The form to be given to the tenon requires consideration; some carpenters introduce it at the lowest part of the girder, which in a great degree destroys its stiffness; being a sixth of the depth, it should be placed at one-third of the depth from the lowest side. Horizontal timbers intended to bear great weights should be always notched on their supports, in preference to being framed in between them, and this rule is applicable to inclined timbers, as common rafters and braces; all the pressures to which they are subjected should be brought to act in the direction of their lengths, and the form of the joint should be such as to convey the pressure as much as possible into the axes of the timber; when subjected to a strain, a partial bearing is liable to very serious disadvantages, particularly in bridges.

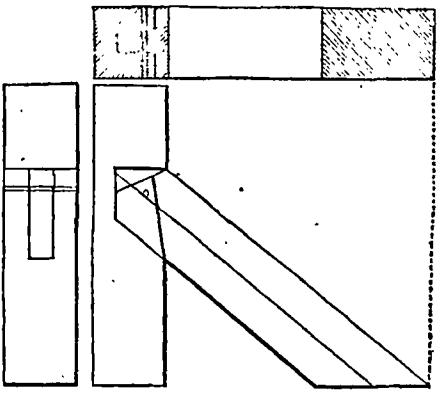


Fig. 2067. TENONS.

Where the mortise is to be made in the upright timber, and the tenon to be cut on another inclined, as in a brace to a partition, a bevelled shoulder is cut on the inclined piece, and a sinking made in the upright post to receive it, the pin which secures it in its mortise passing through the tenon.

The bevelled shoulder adds greatly to the strength of a mortise and tenon joint, and should never be dispensed with; it renders the junction of the two pieces of timber more exact, and makes the abutments of all the fibres stronger and more capable of resistance.

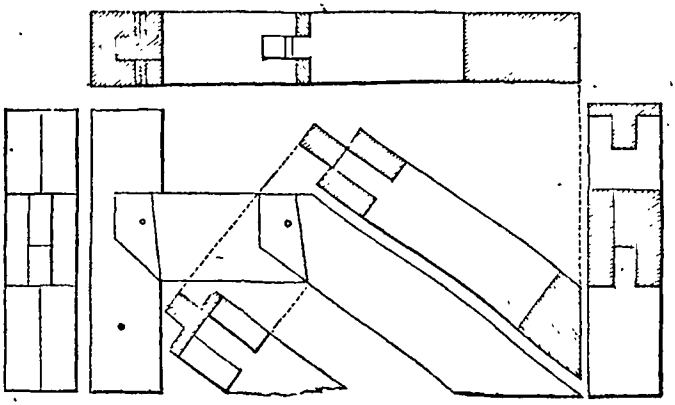


Fig. 2068. BEVELLED SHOULDER JOINTS.

The common method of effecting such a junction does not occupy so much time or labour, but is not so effective; it is usual to drive one or two wooden pins through holes bored for the purpose at right angles through the timber, in which the mortise is made as well as through that which has the tenon.

Boring the hole for the pin requires to be nicely performed, in order that it may draw the tenon tight into the mortise prepared to receive it, and make the shoulder butt close into the joint, without running the risk of tearing out a portion of the tenon beyond the pin: square holes and square pins are preferred to round, as they bring more of the wood into action, and there is less liability to split.

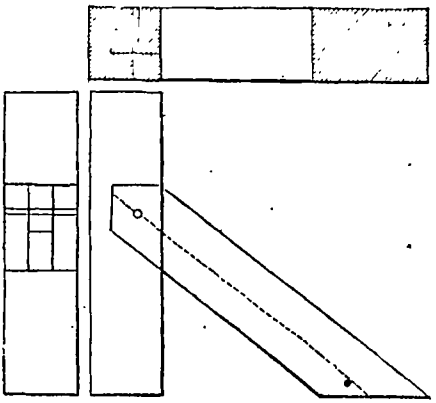


Fig. 2069. SHOULDER JOINTS.

Fox Tail Wedging, adopted by ship carpenters, is made with long wooden bolts, which do not pass completely through the timbers, but take a very fast hold; they are subject to be crippled in drawing, if they are too nicely fitted; this is remedied by placing a thin wedge into the hole previous to the insertion of the wooden bolt, which, when driven, is split by the wedge, and thus squeezed tight to the sides of the hole.

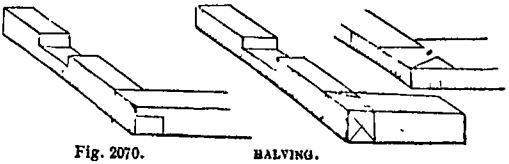


Fig. 2070. HALVING.

Bond Timbers and Wall Plates require to be carefully notched together at every angle and return, and scarfed at every longitudinal joint.

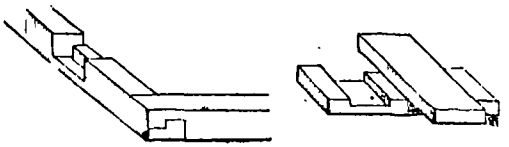


Fig. 2071. HALVING.

To make a good tie joint requires great attention on the part of the carpenter; and for uniting wall plates the dovetail joint is sometimes adopted: if the effects that shrinking may produce be taken into consideration, the more usual system of halving is decidedly preferable; whenever this joint is employed, a stout pin of tough oak, or an iron bolt, should be driven through to render it secure, and, where there is the slightest tendency for one piece to slide from the other, iron straps must be used.

Fig. 2072. DOVETAIL JOINT.

Timbers which are laid upon the Plates, and intended to act as ties, should be cut with a dovetail, and let into the timber it is to secure; generally, where they cross at right angles, *halving* or cutting away the moiety of each is adopted, and one is let into the channel cut in the other.

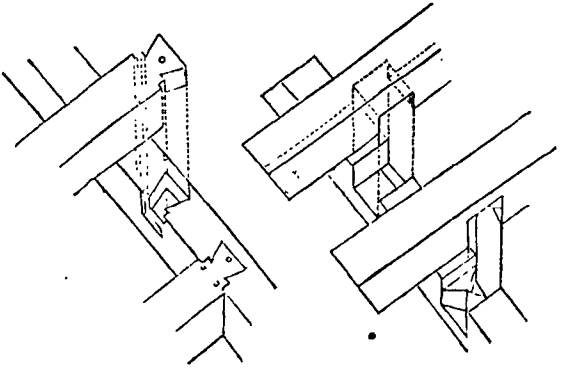


Fig. 2073. CAUKING JOINTS. Fig. 2074.

Cauking, or dovetailing a cross, as used for fitting down tie-beams or other timbers upon wall plates, should never be made too large, nor too near the ends of the plates, the grain of the wood, if cut across, being very liable to split off; it may be observed that the dovetail joint so frequently referred to is not so termed on the Continent, but is universally known as the swallow-tail, *queue d'hirondelle*.

For joining two pieces of timber together *notching* is the most common and simple method; for, when four angles are to be formed, the surfaces of one piece are both parallel and perpendicular to those of the other; a notch may be cut out of one piece (fig. 2071.), the breadth of the other, which may be let down on the first, or the two pieces may be both notched to each other, and then secured by an oak pin: this is the best practice when each of the timbers is equally exposed to a strain in any direction. When one piece has to support the other transversely, the upper may have a notch cut across it, to the breadth of two-thirds the thickness of the one below, which must also have a similar notch cut out on each upper edge, leaving two-thirds of the breadth of the middle entire, by which means the strength of the supporting or lower piece is less diminished than if a notch of less depth were cut the whole breadth: such joints are particularly adapted for purlins, when let down upon the principal rafters.

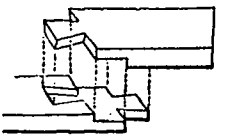


Fig. 2075.

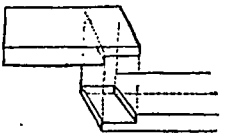


Fig. 2076.

Lapping is performed in a variety of ways, either by simply halving the end of each timber, or by halving and dovetailing; in the latter case the timbers act as a tie, and cannot be readily pulled asunder.

In these joints the greatest attention is required to make the several parts abut completely on each other, as the least play or liability to motion at once destroys their efficacy; the butting joints, being slightly tapered to one side of the beam, require very moderate blows with a hammer to force them into their place; if driven too hard, the parts will be liable to strain, and the abutments to split off: it is better sometimes to leave the abutments open, and afterwards drive in a small wedge, which, if made of hard wood and not likely to compress, is an excellent substitute; iron has been said to injure the fibres of the timber, from its too great hardness, otherwise it is well adapted for the joggles and wedges.

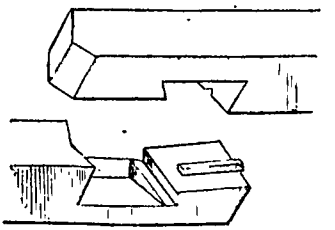


Fig. 2077.

Two pieces of timber may be united in such a manner that they preserve the same breadth and depth throughout, which is of great importance in the construction of beams for bridges or roofs of considerable span: the length to be given to the scarf must depend upon the force that will cause the fibres of the timber to slide upon each other, and that for oak, ash, or elm should be 6 times the depth of the timber, in fir 12 times; but where bolts are used so much is not required in either case: the simplest method for uniting the ends of two timbers is by cutting away an equal portion of each, and letting one down upon the other.

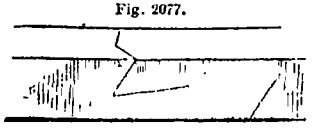


Fig. 2078.

Timbers united together by a number of such cuttings, afterwards united and bolted through or hooped round with iron, are capable of sustaining great resistance: a stirrup-iron at each end holds the timbers in their places, and one or more bolts is sufficient to prevent their being drawn asunder.

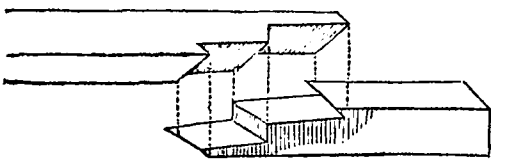


Fig. 2079.

The carpenter frequently exercises great ingenuity in joining timbers of considerable scantling, and, by the introduction of iron or small cubes of harder wood into the joints, can prevent their being thrust or drawn out of their position either longitudinally or laterally.

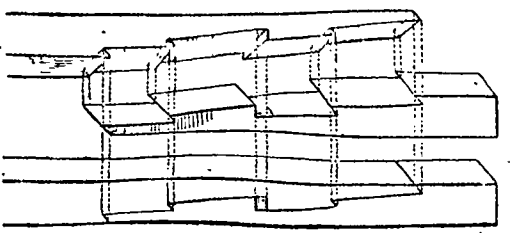


Fig. 2080.

The Scarfing of Girders and Beams, which the French engineers term *Traits de Jupiter*,

from their resemblance to forked lightning, have a great variety of forms given them, and are sometimes bolted through, at others strapped round with strong hoops of iron: where bolts are dispensed with, it is perfectly clear that the joint cannot have half the strength of an entire piece: where the stress is longitudinal, two irons put on each side

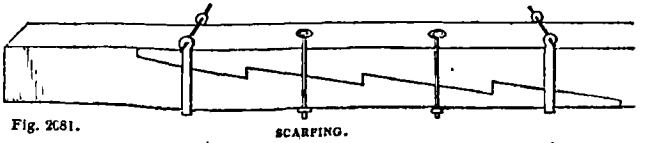


Fig. 2081. SCARFING.

will prevent the scarf that is merely indented from pulling asunder; but such a provision will not maintain the constant horizontal position of the timber.

When a scarf is forced to its bearings by the introduction of keys or wedges driven tight, they sometimes receive an additional strain, and it is often found advisable to omit them, and to bring the joints to a bearing by some other means before the bolts are inserted: when keys are made use of they should be of very hard wood, having a curled grain, which resists the insertion of the fibres opposed to it.

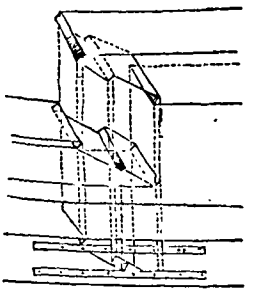


Fig. 2082. SCARFING.

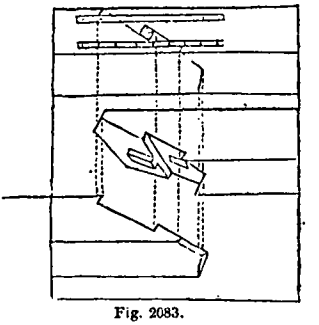


Fig. 2083.

To prevent lateral movement cogging is adopted, in addition to the ordinary method, and a small tenon or cog is left upon a portion of the scarf, which enters into a notch prepared in the piece which is to cover it: beams intended to resist cross strains require to be lengthened more frequently than any others, and from the nature of the strain a different form of scarf must be made use of to that which is required for a strain in the direction of its length: when timber is subjected to both strains, the cross strain is that which demands the greatest attention: where a floor is supported, the scarfing requires to be further secured by iron bolts made to pass through a longitudinal piece, laid to cover the under side of the joint.

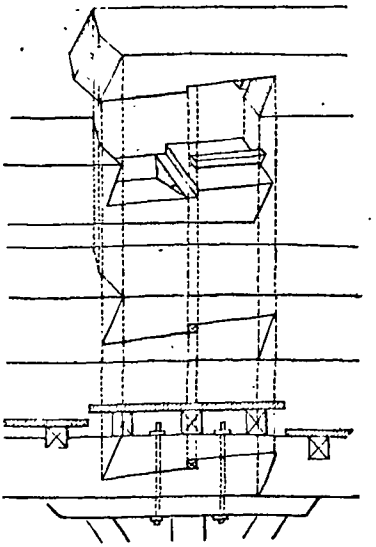


Fig. 2084. SCARFING.

Bearing Posts, when used to support the floors of a magazine or warehouse, are generally formed exactly square: to obtain their dimensions, we must refer to what has been already stated in reference to the weight the several timbers will bear in the direction of their length, or the weight they will carry previous to the compression of their fibres: some timber will support, whilst that of another quality will suspend the most; therefore in the selection of story-posts, we must pay attention to these peculiarities. Iron, however, is generally used for these purposes, in consequence of its horizontal sectional area occupying less space than timber of the same strength.

When a tie-beam is mortised through to receive a king or queen-post, and it is necessary to provide for the means of holding it up, the tenon should not be pinned through, as it is not advisable to depend entirely on the pins for the support: the tenon should be cut like a half dovetail, or in a sloping direction, on one side, and left straight on the other: the mortise-hole should be so cut that the lower end

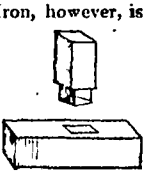


Fig 2085.

can just pass; when it is in its place, a wooden key or wedge is driven tightly on the straight side, which forces the tenon against one side of the mortise-hole, and prevents it effectually from being drawn out: oak or iron may be added, or an iron strap may be applied.

Tenons may be wedged at the end, but to do this they must be made long enough to pass entirely through the mortise: two saw cuts are then made across it, and the wedges are driven home: the tenon sometimes splits, but not sufficiently to injure its strength. When in machinery it is not practicable to cut the mortise through, the fox-tail wedging is adopted; the tenon is made to fit the mortise exactly; the wedges are loosely put into the saw-cuts, as before, and the whole is driven to its place: when the wedges touch the bottom of the mortise, they cause it to spread, and thus hold the tenon firmly in its place.

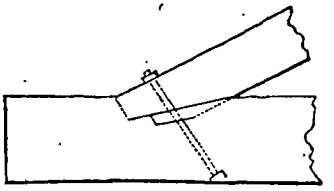


Fig 2086. PRINCIPAL RAFTERS

Dovetailing in some degree resembles mortising and tenoning, and is more adapted to uniting together the angles of framework: the feet of the rafters require the mortise and tenon to be carefully made, and the thrust is destroyed to a certain extent to obtain greater strength: a portion of the rafter is tenoned into the tie-beam, and another small part is let into the upper part of it; both rafter and tenon are cut at right angles with the inclination of the roof: in one example the rafter has two bearing shoulders in its depth, one behind the other, in addition to the tenon which unites them. Struts and braces which are loaded require but little mortising to keep them from sliding out of their places; the more flat their ends can be cut, the more efficient will they be: the shrinking of timbers sometimes occasions them to become loose, particularly where there is not much stress upon them.

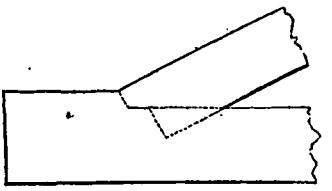


Fig. 2087.

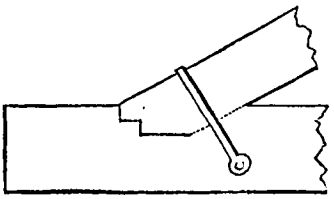


Fig. 2088.

King-posts, queens, and principal rafters, which are subject to great strains, should have iron straps or ties, when they unite with the tie-beam, and an iron strap should embrace the head of the kings and queens, and unite with the principal rafters, the feet of which in large buildings sometimes have their abutment in a cast-iron shoe, which prevents the splitting off the end of the tie-beam.

The ends of king or queen posts may have a screw-bolt passed into them, which allows the nut to be turned at pleasure, and thus the framing may be tightened again, when shrinking of the timbers renders it necessary: this in many instances is preferable to the iron strap, and keys or screws put in the ordinary way.

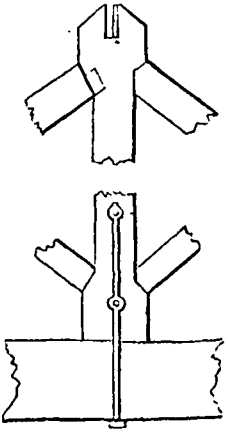


Fig. 2089. KING-POSTS.

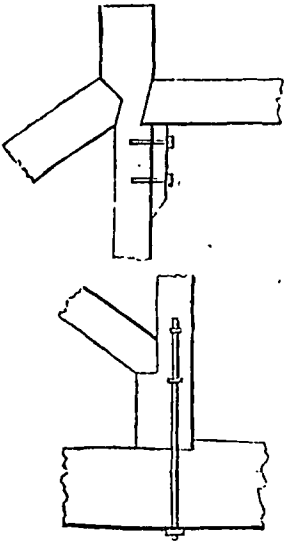


Fig. 2090. QUEEN-POSTS.

Whatever form we adopt for the butting joint, we must be careful that all parts bear alike, for in the general compression the greater surfaces will be less affected and the smaller undergo the greatest change; when all have come to their bearing they should exhibit an equally close joint, and as large timbers are moved with some difficulty, the joint cannot be often put to the test of trying whether it fits nicely; it must therefore be set out with great precision, and worked with regard to its

lines with exactness; a very small portion of a tie-beam left at the end is sufficient to withstand the horizontal thrust of a principal rafter, and blocks may be used at the ends where the rafters abut to give additional strength.

Scarfing a Timber in a perpendicular Direction. — When the top surface is divided into nine squares, if four are cut down, the other five serve as tenons to enter into as many vacant spaces left in the piece of timber placed upon it; or two may be cut away, as in the side figure, to receive a tenon left on the upper piece.

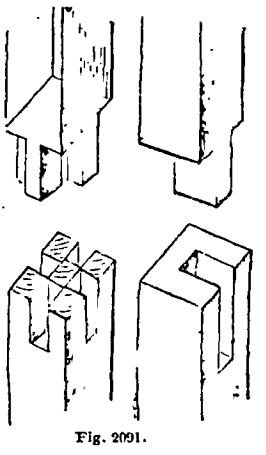


Fig. 2091.

Partitions and Framing for the outside of Buildings, &c., are a species of timber walls, usually covered with lath and plaster, and formed of upright posts, mortised into a head and sill, braced in different directions, and filled in with quarters: the posts are placed at the extremities, as well as at the sides of all doors and openings. When a partition dividing two or more rooms has a bearing which is perfectly solid throughout, it is better without braces; the posts or quarters have only then to be maintained in an upright position, which is effected by driving pieces between them horizontally, so as to strut them, and prevent their bending. Where they rest upon joists, which are liable to shrink, and yield to a weight placed upon them, the partition should be trussed in a manner to throw its load on the parts able to sustain it: in most houses we find great neglect upon this subject, which occasions cracking in the cornice, inability to open and shut the doors, and many other inconveniences.

The thickness given to partitions which do not exceed 20 feet in length is 4 inches: the posts are then 4 inches square, and the other timbers 4 by 3: when they are of greater extent, they should be increased in thickness: when it is required to make a doorway in the middle, the truss may be formed by the braces, the inclination of which should be at an angle of about 40° with the horizon. When the doors are at the sides, the truss may be formed over the heads; the posts should all be strapped to the truss, and the braces halved into the upright posts.

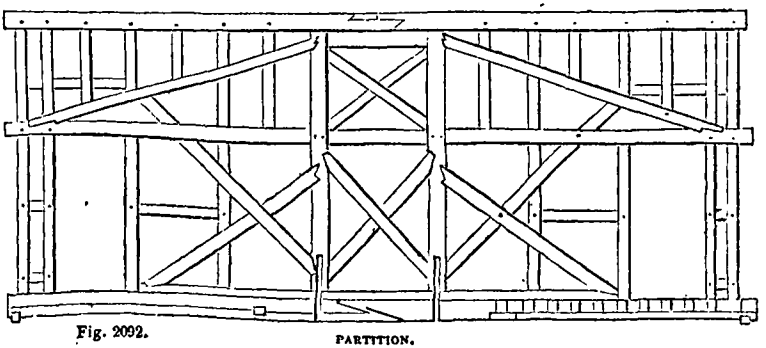


Fig. 2092. PARTITION.

The weight of a square of quartered partition may be estimated at from 12 cwt. to 18 cwt., and every precaution should be taken to discharge its weight from the floor on which it is placed, to the walls, which are its best points of support: in ancient timber houses, mills, &c., the fronts or external sides are formed of upright posts, placed at a distance equal to their scantling; these are mortised and tenoned into a top and bottom plate, which serves also to carry the floors: the posts at the angles are of a larger scantling, and into these, which form openings for doors and windows, are framed horizontal pieces, which serve for heads and sills: braces are then introduced, crossing each other, like a St. Andrew's cross: above the lintholes, and beneath the sills, short quarters or punchions fill in the space, and the whole are mortised, tenoned, and pinned together. The framing should be placed on brickwork, or a wall of masonry, so as to be kept quite clear of the ground.

Floors. — When the bearings are equal, if joists of the same width, but of different depths or thicknesses, are used, their strength is increased in proportion to the squares of their vertical thickness: when the joists are but 6 inches deep, they are in strength to those of 8 inches in depth, as 36 to 64, the square of 6 being 36, and that of 8, 64. The

quantity of timber in the one case to that of the other is as 4 to 3, so that one-third more timber gives a strength double that of the other.

Where square oak joists are used, and the bearing 12 feet, their scantlings should be 6 inches, and laid at a similar distance apart: such a floor contains the same quantity of timber as if entirely formed of 3-inch plank: the strength of timber being as the square of its vertical thickness, it results that the strength in these two instances is 2 to 1: the floor composed of 3-inch plank is only half the strength of the other; but had the whole been formed 6 inches thick, instead of with joists 6 inches apart, it would have been four times as strong, the square of 3 being 9, and the square of 6, 36.

Naked Floors are divided into *single-joisted, double,* and *framed, floors;* and it must be remarked that unsawn timbers are considerably stronger than planks or scantlings cut out of a round tree: when a tree is cut longitudinally, and formed into two pieces, these will support less than they would do when united in the original tree, arising from the circular concentric rings which compose the tree being cut through, which renders the timber more compressible on one side than on the other; and as the texture is less close where it has been sawn, it is also more susceptible of change from humidity on alternation of temperature.

Joists, whose width is less than half their vertical thickness, are subject to twist and bend, if not strutted; and, for this reason squared timber was usually employed by the builders in the middle ages; and we have numerous examples, four or five hundred years old, where the timber selected has the pith in the centre, and the concentric rings nearly entire, being in a sound and perfect condition: experience also teaches us that timber, whether sawn or unsawn, used for a floor of 16 feet bearing, composed of 12 joists, 8 inches square, placed at a distance of a foot apart, is much stronger than another of 24 joists, 8 by 4, placed edgeways, at a distance of 6 inches apart, although there is the same quantity of timber in both cases.

Single-joisted Floors consist of one series of joists, which ought to be let down or halved on to wall plates of a sufficient strength and scantling to form a tie, as well as a support to the floors; each joist should be spiked or pinned to the timbers on which it lies: wherever fireplaces occur, and the joists cannot get a bearing on the wall, they are let into a trimmer or piece of timber framed into the two nearest joists that have a bearing; into this the other joists are mortised. As the trimming joists support a greater weight, they must be made stronger than the others, and should have $\frac{1}{8}$ inch additional thickness given to them for every joist they carry. When the bearing exceeds 8 or 9 feet the joists should be strutted, or they will have an inclination to turn sideways: the joists in use, being generally thin and deep, require strutting on all occasions, and a rod of iron is often passed through them, which, being screwed up after the strutting pieces are placed, gives the entire floor great solidity and firmness. The weight of a square of single-joisted floor varies from 10 cwt. to 1 ton, and the joists should never extend to a greater bearing than 20 feet in ordinary cases.

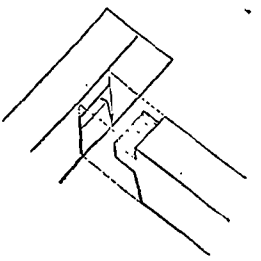


Fig. 2093.

To find the Depth of a Joist, when the length of bearing and breadth in inches is given: divide the square of the length in feet between the supports by the breadth of the joist in inches, and the cube root of the quotient multiplied by 2·2 for fir and 2·3 for oak, gives the depth in inches: a single-joisted floor, which has the same quantity of timber as a double floor, is considerably stronger, particularly if properly strutted, than the latter. The plates, bedded on the walls, upon which the joists are to be tailed down, should have their depth equal to half that of the joists, and their width half as much more; in many instances the plates are not bedded entirely in the wall, but have one half resting beyond the face on corbels let into the wall, at a distance of 6 feet apart. To form the entaille or dovetail great care should be used, to prevent the joist from drawing out of its place, when once pinned down.

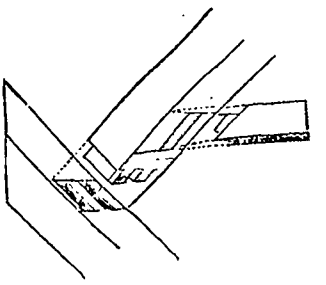


Fig. 2094.

Double Floors are formed of *Joists, Binders,* and *Ceiling Joists:* the binders rest upon the plates bedded on the walls, and serve the purpose of supports to the joists which are bridged on them, as well as to the ceiling joists, which are pulleys mortised into their sides: when the depth of a binding joist is required, the length and breadth being given, divide the square of the length in feet by the breadth in inches, and the cube root of the quotient,

multiplied by 8·42 for fir, and 8·53 for oak, will give the depth in inches: when the length and depth are given, and the breadth is required, divide the square of the length in feet by the cube of the depth in inches, and multiply the quotient by 40 for fir and 44 for oak, which will give the breadth. The above rules suppose the binders to be placed at a distance of 6 feet from each other.

Binding joists must be framed into the girders, and care must be taken that the bearing parts fit the mortise made for them very accurately: the tenon should be one-sixth of the depth, and placed at one-third of the depth, measured from the lower side. When binding joists only are employed to carry the ceiling, their scantlings may be found in the same manner as those of ceiling joists, which are small timbers, and only of a sufficient thickness to nail the laths to; when their length and bearing are given, their depth may be found by dividing the length in feet by the cube root of the breadth in inches, and multiplying the quotient by 0·64 for fir, or 0·67 for oak, which will give their depth in inches. Ceiling joists are usually notched to the under sides of the binding joists, and nailed to them; this is better than mortising, which weakens the binder, and gives more labour.

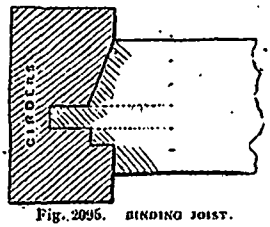


Fig. 2095. BINDING JOIST.

Double-framed Floors depend entirely on the girders for their strength; their vertical thickness should be not less than one-eighteenth part of their length: the practice of halving them down, and reversing their sides, is only beneficial for the purpose of ascertaining the soundness of the interior of the timber used; whenever the concentric rings are cut through, and the series of inclosed cones destroyed, the timber loses a portion of its natural strength: a girder or piece of timber that has its breadth equal to double its thickness, when placed edgeways, will carry considerably more; for with pieces of equal length, the strength is in a compound ratio to the squares of their depth or vertical thickness and their width; thus, a piece of timber 16 inches by 8, placed on edge, is to the strength of the same piece placed flat, as the square of 16 multiplied by 8, is to the square of 8 multiplied by 16, or, as 2048 is to 1024, or as 2 is to 1; but this piece of 8 by 16 inches would not carry the half of what a piece 16 inches square would do.

To find the Depth of a Girder, when its length of bearing and breadth are given. Square the length in feet, and divide this product by the breadth in inches; the cube root of the quotient, multiplied by 4·2 for fir and 4·34 for oak, will give the depth in inches. To find the breadth, when the length and depth are given, divide the square of the length in feet by the cube of the depth in inches, and the quotient multiplied by 74 for fir, or by 82 for oak, will give the depth in inches: in giving the above rules it has been supposed that the girders are not placed more than 10 feet apart; when that distance is exceeded, they must be increased in proportion.

The Strength of Girders, or any other piece of timber of the same length and thickness, are in proportion to the squares of their depth; but when the thickness and depth are both to be taken into consideration, then their relative strengths are in proportion to the square of the depth multiplied into the thickness: when the length, breadth, and thickness are taken together, the weights that will break each will be in proportion to the square of the depth multiplied into the thickness, and divided by the length: and if we multiply the square of the depth of each piece into its thickness, and divide each product by its length, each quotient will give the proportionate strength of each piece of timber. When it is required to have girders of greater length than 20 feet, it being difficult to obtain timbers of that scantling, it is usual to form them of two pieces trussed and bolted together: the core of such trusses must not be let close into the grooves of the side beams, but must be well secured both at the ends and middle, or a weight laid upon the girders should not bend the braces, which would render them of no use; to prevent this effect, they should not be fitted in close; then the girder can never bend materially, as the side beams cannot do so without shortening their length, and in the act of bending, the braces force against the ends, and act on an opposite direction to the side beams. When the truss is tightened, it is necessary to grease the head of the king-bolt, in order that it may slide freely by the ends of the trusses; and when the workman by a smart blow drives the head of the king-bolt, another should be ready to turn the nut at the same time, so that the girders may be made to camber about an inch in a length of 20 feet: all the stiffness obtained on trussing a girder is by forcing the abutments, or cambering it; but this to a certain extent injures the natural elasticity of the timber, and in the course of a short time the truss becomes a load and useless: this has caused the introduction of an iron truss, with an iron tie as an abutment, and thus the compression which took place on the abutments is in a great degree removed.

The common method of trussing girders is very defective, and where the depth is

limited iron must be employed; a cast-iron girder is much more simple, and less expensive, than iron framing introduced into timber as the means of strengthening it; but as this cannot always be readily obtained, it will be necessary to describe other methods that have been adopted in trussing girders: one of the most simple and best methods is by cutting the girder, for a considerable distance, in the direction of its length, and wedging the upper portions upon the middle, and then hooping it round with iron straps.

Another method is to place two pieces of timber like rafters on the upper part of the girder, and which has abutments cut to receive their ends; a stirrup iron passes over the centre, or one is placed on each side at a little distance from it, and these ties are placed square with the rafters: another method is a kind of queen truss; two rafters abut against a straining piece, and are let in, as well as hooped round by stirrup irons; this plan is varied by omitting the straining piece, and introducing an oak block to form the upper abutment.

As timber resists more when pressed longitudinally, or in the direction of its fibre, than when it is acted upon laterally, it is advisable to substitute for the piece of oak a plate of iron or lead, or some other incompressible metal; the rafters can then be adjusted, to form a common joint in the middle, and a complete truss; the girder should be suspended in the middle, whilst the iron ties at the extremities are tightened by this means: the girder may then be made to acquire greater stiffness, by having a curvature given it, fitted up with other pieces of timber cut to the camber, and made to fill up the voids between the rafters and the girder. It has been satisfactorily proved that a piece of timber curved on its upper side, and its extremities secured, to prevent its springing, when placed on two supports, and loaded in the middle with a weight sufficient to make it bend one-third of its thickness, if strengthened by another piece of timber, so as to preserve its curve and form an arc, will sustain a weight more than double without yielding. Forming floors with joists of small thickness, where camber timbers are united with straight, so that they are not permitted to spring, is perhaps the most simple method of making them strong; thus for floors where the joists have a bearing of 24 feet in the clear, the depths are made in two, the lower 7 inches in thickness, and the upper, 13 inches, are made up, after cutting the superior surface in a curved form, by laying on them others bent to the curve, by means of iron straps 3 or 4 feet apart, taking care to give to this curve half the difference between 7 and 13, viz. 3 inches, so that the lower joists will be in depth 7 inches in the middle and 4 at each end; we shall thus have joists sufficiently strong to bear any ordinary weight that can be put upon them. Girders may be formed in this way, by uniting several such joists side by side, so that for a bearing of 24 feet, where they ought to have a depth given to them of an eighteenth of this width, or 16 inches, it may be thus done: supposing the under joists to be 7 inches in depth, 9 inches more is required, the half of which is 4½ inches, which is the amount of curvature to be given to the upper joists; instead of cutting away any portion of the lower joists, the curved top may be given by furring out the 4½ inches in the middle and letting it fall off to nothing at the extremities: on these joists so prepared, with a curvature on the upper sides, the upper joists are laid, and then bent to the lower ones, and secured by means of iron straps: a series of such joists bound together or united forms a guider.

Some builders have taken advantage of the difficulty of crushing timber in the direction of its length, and applied it very ingeniously for obtaining strength in a girder: a saw cut is made across the middle of the girder to the depth of one-third its vertical thickness; it is then bent upwards, and when the cut has opened sufficiently, a wedge is introduced into it, thus making it camber, and consequently stiffer, whence it can bear a greater weight; Parent has proved that joists so cut and prepared are one-sixth stronger than those of the same scantling unsawn.

Another method of building up a girder, or strengthening a beam, was adopted by Smeaton, which was by bending a piece into a curve, and securing it from bending back by straps and bolts; the additional stiffness so obtained is considerable, particularly if the pieces are properly bolted, or prevented from sliding on each other; the thickness of the bent pieces should be made about the fiftieth part of the bearing, and as many should be added as will increase them to the depth required; when the whole depth of the curved pieces exceeds half the depth of the guider, then straight pieces must be added to the under side, so as to make the entire depth of the straight part exceed that of the curved part: care must be taken, when pieces cannot be found of sufficient length, that the joints do not come in the middle of the length of the lower half of the girder.

Roofs, or the Coverings of Buildings, which protect them from the weather, serve also to bind them more firmly together, and a knowledge of the strains to which the various timbers are subjected, as well as what should constitute their relative strength, is one of the most important studies of mechanical carpentry: the various inclinations that have been given to them is perhaps dependent upon the nature of the climate where they are used. In northern latitudes, where there is more rain, and the cold is greater, the pitch is made higher; this decreases as we approach warm and dry climates; in Egypt, the covering of

their houses is almost flat, and forms a terrace, and this is the case in some parts of Italy. The inhabitants of the north have pitched their roofs very steep, for the purpose of more easily throwing off the water; for though it rains more frequently in temperate than in warm climates, the rains are heavier in the latter, and consequently require less inclination in the roofs to carry them off; and the temperature is so elevated, that they become dry immediately the rain is over. Where the rain is more frequent and less heavy, the air is more humid, the water has more difficulty to run off, and the roof takes longer time to dry; consequently a greater inclination in some degree compensates for this. The inclination of the roof depends also upon the material that forms its covering: pan tiles require less inclination than flat or plain ones, as the water collects in the hollow, and more easily runs away, and is not so much subject to be driven by the wind under them, as where flat tiles or slate is employed: in very rainy weather, and when fine rain is falling, the under parts of slates and other coverings which have a trifling inclination is almost as wet as the upper, as the water is induced to flow up by capillary attraction: when snow is melting, this is often found to be the case, and the more so, the more smooth and compact the materials which form the covering are; even between two panes of glass, the water will remount between the lapping surfaces, and it becomes necessary that a sufficient inclination should be given to counteract this effect.

As the inclination to be given to roofs, then, should increase with the latitude, we must commence, after quitting the tropical regions, with something like a fall; we find, for the latitude of Athens, which is 38° 5′, if we subtract 23° 28′, which is that of the Tropics, there will remain 14° 37′ as the inclination to be given to roofs in that city: and upon examining the roof of the Propyleon, we find its inclination to be 14½°; that of the Parthenon 15½°, and that of the Erechtheum 15°. Rome is situated in 41° 54′ north latitude, and deducting that of the Tropics, we have 18° 26′ remaining, which affords us the inclination indicated by the term *tertiarium*, as used by Vitruvius: speaking of Tuscan temples, he observes, "stillicidium tecti absoluti tertiario respondeat," which makes the entire height of the roof, from the gutter, one-third of the length of the horizontal line; this system gives precisely an inclination of 18° 26′. The porticoes at Rome do not agree with this inclination, for they vary between 23° and 25°, and which was owing probably to the material with which they were covered being different, in order that the proportions of the façade should not be made subservient to necessity: when we give to the height of a roof the fifth part of its span, we have an inclination of 21° 48′, which is sufficient for flat tiles or slates, and in our latitude we usually make the pitch for pan tiles 27° 24′, for slates 33° 24′, and for plain tiles 25° 24′.

The simplest construction employed is undoubtedly that which roofs in an excavation made out of the solid rock or earth. Trees pitched one against the other in a triangular form, and well secured at the base, would serve for rafters, which would support either branches, shingles, or cleft pieces laid one over the other, to keep out the weather; upright boarding or palisades to close the gables or ends would then constitute it a rude dwelling.

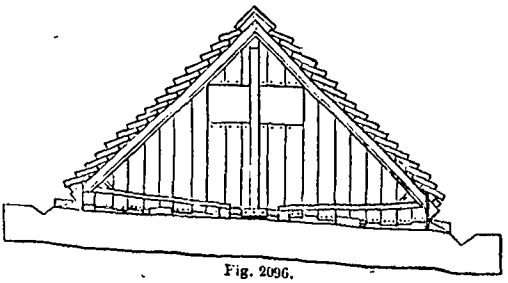


Fig. 2096.

An improvement upon the above method would be that of raising the roof sufficiently above the ground to enable the inhabitants to walk erect beneath it without sinking a hole in the earth, and which in many situations would be damp, and perhaps occasionally filled with water.

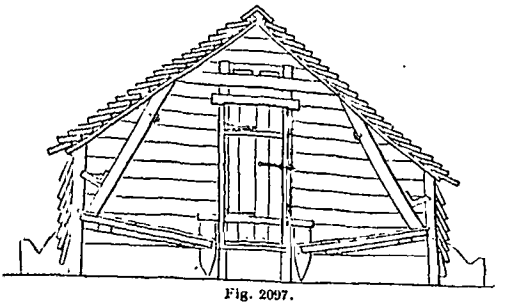


Fig. 2097.

Roofs, Vitruvius informs us, were covered with reeds, and sometimes with clay mixed with straw; and Pliny observes that the ancients made use of the shells of tortoises for the same purpose. In Switzerland and in Germany shingles split out of oak and fir are, on account of their lightness, preferred to any other covering.

In some of the ancient works on carpentry we have designs for primitive huts, with the principals curved or set out like the pointed arch, or with the ribs of a whale so placed that they are made to carry the weight of the roof.

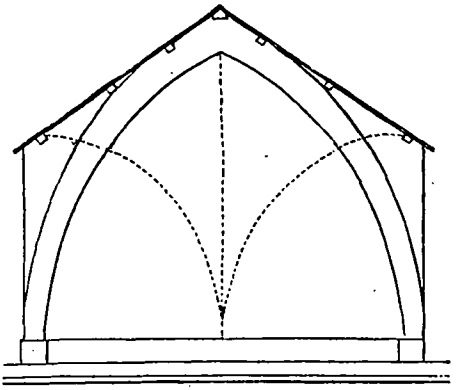


Fig. 2098.

The roof is that portion of a building which requires the greatest degree of skill, and where the aid of science is more essential than in any other; in our primitive timber houses we observe that much of their construction bears the impress of the labour of the ship-builder rather than that of the carpenter; in the Weald of Kent and Sussex many fine timber structures are still remaining, in which the skill of the carpenter seems borrowed from the mason, for the mouldings and forms introduced are evidently imitations of those executed in stone: oak is the material generally employed, and in some instances the corner posts are 24 inches square, and in a perfectly sound state; the roofs are generally highly decorated, the barge boards and pendants which accompany them delicately carved, and present an endless variety of design.

Buildings are sometimes found rudely braced by such curved ribs, and which bear a resemblance to a boat turned upwards: these ribs are occasionally made by nailing or pinning together short lengths of thin deal, and securing the plate on which the roof pitches to their sides: rafters laid with a slight projection to throw off the water, and a number of purlins resting on them in a longitudinal direction, require nothing more than the tile, slate, or metal covering to complete the roof.

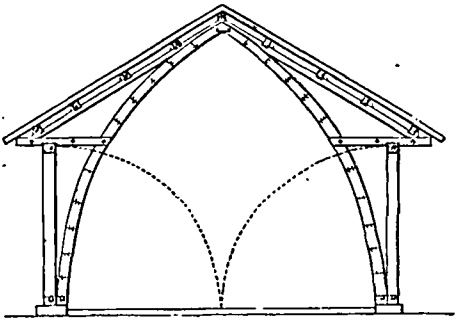


Fig 2099.

When two or more stories are required, the same construction may be made use of; the upright posts and partitions contribute much to the strength of the building, and the curvilinear braces extending from the ground to the ridge of the roof, where they do not interfere with the convenience of the apartments, are of considerable service.

The timber houses in Switzerland, which generally consist of two stories, are fine examples of cheap construction, and when placed upon a basement of masonry, and preserved from the heavy rains, are as durable as if built entirely of stone. The roofs are flat, covered with shingles, laid with a good lap one over the other, and

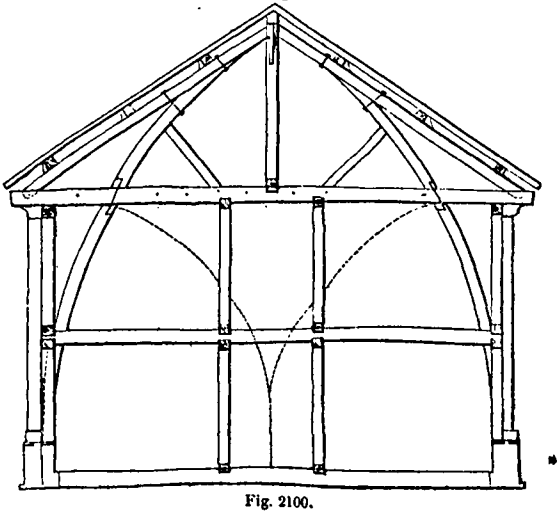


Fig. 2100.

sometimes the fronts of the house are cased with courses of wooden tiles with ornamental edges, placed over each other like plates of mail.

Circular Chambers are obtained in a roof by keeping up the tie-beams, but at the expense of their utility: in such cases the external walls should be of sufficient thickness to resist the outward pressure of the feet of the rafters, which cannot be sufficiently held in by the ribs of the curves, or the braces attached to them.

Where semicircular ribs are introduced, with their lower ends framed into the girders of the floor below, a part of this objection may be removed, and a very convenient apartment obtained: the outer walls should only be carried up to such a height that they can have their crowning-plate affixed or tied to the braces, which are framed into the collar above: this kind of roof is very common on the Continent, and is evidently derived from ancient examples; to light these apartments a dormer window is constructed, which has its top a little below the collar, or hammer-beam, as it is sometimes termed; the chambers being appropriated for rest were called dormitories, from whence these windows probably derived their name.

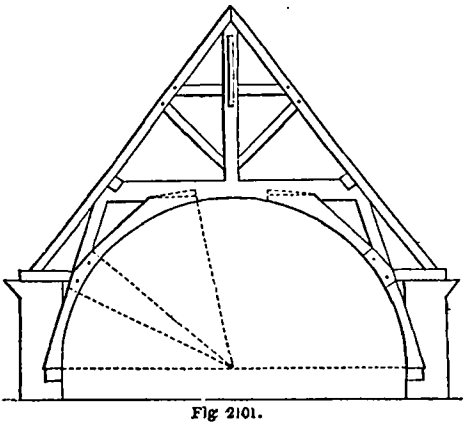


Fig 2101.

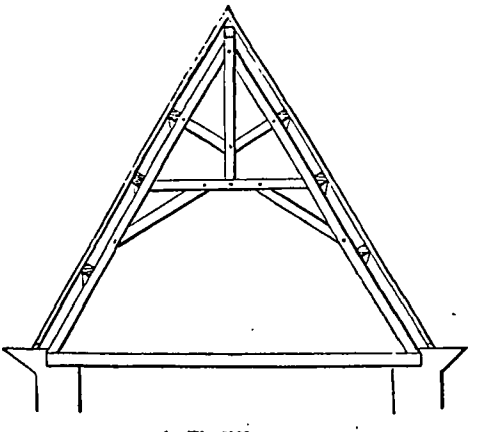


Fig. 2102.

In many of our parish churches we find roofs whose length of rafter is equal to the entire width of the building; at about half their height is thrown in a collar, on which stands a tree-post, strutting up the principals: beneath the collar are usually thrown in two braces, which are framed into it and the rafters; such a roof, with a tie-beam to hold in the plates which receive the rafters, endures for ages.

Where the tie-beam is omitted, for the purpose of giving a polygonal character to the ceiling, it is necessary to have the walls of considerable strength: over their entire width is a capping of timber, on which the principals rest, and to which they are firmly pinned.

The walls of our churches where these roofs are introduced are generally 3 feet in thickness, but if the width of the span be great, buttresses are required at every 10 or 12 feet, to resist the thrust which it occasions: by spreading the feet of the rafters the weight of the roof bears upon the entire thickness of the masonry, and further strength and protection are obtained by an additional short rafter, which projects to the outer face of the wall, and carries the eaves out sufficiently to throw off the water, and prevent its doing injury to the construction.

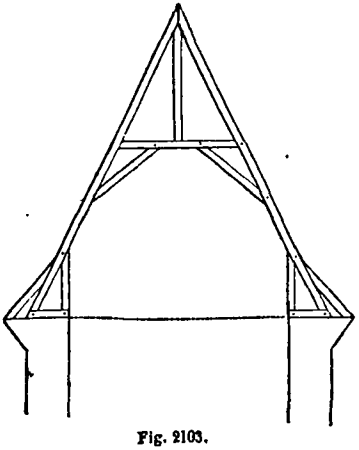


Fig. 2103.

Semicircular ribs, formed by three thicknesses of deal or other timber, and others of the figure of the pointed arch, are occasionally met with, where timber of large scantling cannot be readily obtained; and when well put together and pinned carefully, such a roof has remarkable strength, and will endure for ages.

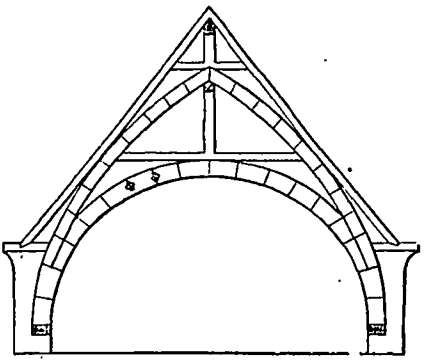


Fig. 2104.

The timber roofs of the middle ages are of high pitch, and formed without any horizontal ties; they are supported by the walls on which they rest, and the thrust of the ends of the principal rafters is counteracted by buttresses of sufficient strength to resist it; indeed the introduction of a tie-beam would have destroyed the effect of carpentry framed upon the principles adopted in masonry. The roofs of our churches are usually formed of pairs of rafters, the feet of which are framed into a piece of timber laid across the thickness of the wall, into which at the other extremity is framed an upright quarter, fair with the inner face of the wall; at about two-thirds of its height a collar is framed, in which is supported the tree or post which carries the ridge: beneath the collar two braces are introduced, which give the contour for the ceiling a half-decagon or semicircular form. The plates are usually made of considerable thickness, and the pitch given the roof is as much as their span: some of the roofs constructed in the fourteenth century are of surprising beauty, both for their construction and workmanship: that over Westminster Hall, finished about 1399, is in extent equal to any; its clear span is 68 feet, and its total length 238 feet 8 inches, and its width 66 feet 6 inches, divided into 13 bays. The skilful arrangement of its timber combines lightness, strength, and beauty, and its pitch is such that the length of the rafters is about three-fourths of the entire span. This roof exhibits perfectly the construction in use before the introduction of tie-beams; and the lateral thrust is prevented by placing at the foot of each pair of principals flying or arched buttresses, of sufficient strength; these principals are placed at about 18 feet apart, and run throughout the whole length of the building, forming 13 severeys or bays of roofing: each pair of principals comprehends one large arch, resting on stone corbels, which project from the wall at a distance of about 21 feet from the base line of the

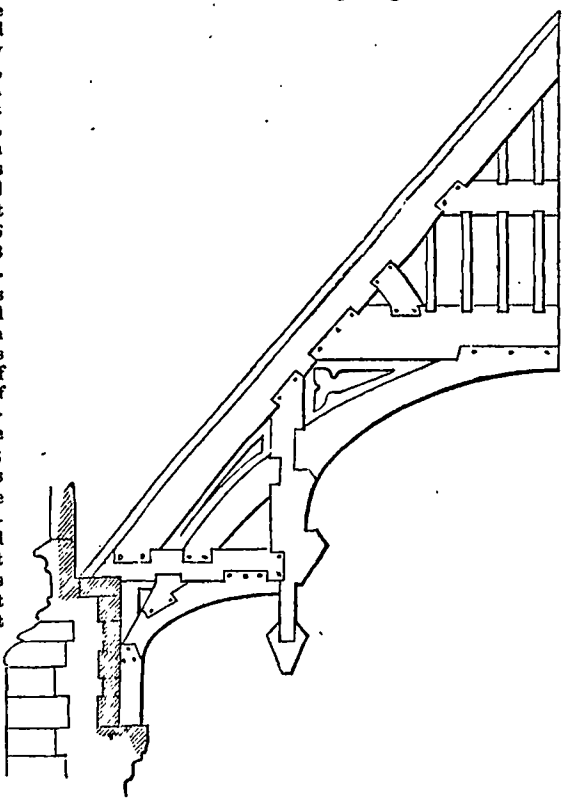


Fig. 2105. ELTHAM HALL.

roof. The ribs that form this arch are framed into a beam, which connects the rafters in the middle of their length: within this large arch is introduced another, which has its springing on a level with the base line of the roof, and this is supported by two brackets, or half arches, issuing from the springers of the main arch; each of the trusses acts like an arch, and by placing their springing below the tops of the walls, a better abutment is obtained.

Eltham Hall is internally 101 feet 4 inches in length, and 36 feet in width, and is divided into 6 compartments or bays; the length of the rafters is about four-fifths of the span, so that it has not so great a pitch as that of Westminster Hall. In this example the arches are obtusely pointed, and struck from four centres. The trusses at Eltham have a greater quantity of timber in proportion to their breadth than those of Westminster, but the walls and buttresses are much lighter.

Crosby Hall, finished about 1470, is internally 69 feet by 27, and is another fine example of these admirable works in oak timber: three ranges of pendants form the chief ornament and variety.

Hampton Court Great Hall was completed about 1537; its dimensions internally are 106 feet by 40 feet; the flattened pitch at the top is a novelty in this kind of construction.

The Hall of Christ Church, Oxford, is 115 feet by 40 feet; that of Trinity College, Cambridge, 100 feet by 40 feet; the New Hall at Boreham, 90 feet by 40 feet; that of the Middle Temple, London, 100 feet by 44 feet; Lambeth Palace, 93 feet by 38 feet; Guildhall, London, 153 feet by 48 feet.

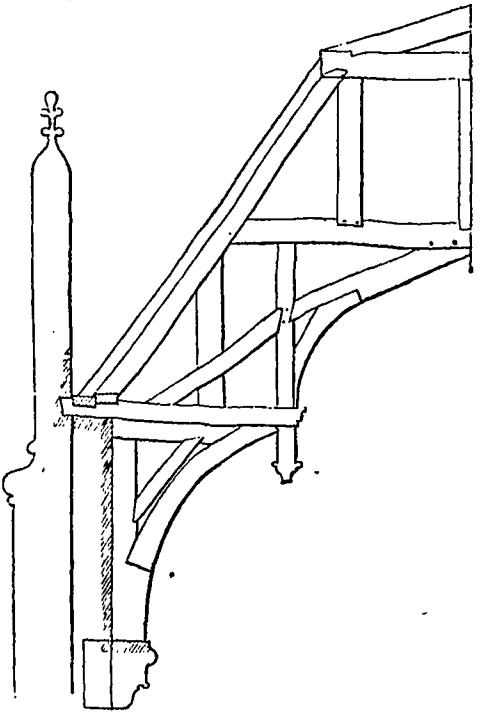


Fig. 2106. HAMPTON COURT.

In examining the principles of the beautiful roofs, of which we have so many remaining in England, we find that the pressure against the walls is sometimes too oblique, and that the buttresses have yielded after the strong plates, laid upon the walls, had given way, as is the case at Eltham. These timber roofs originated in the reign of Edward III., and were common to all large halls: they were executed with the best quality of well-seasoned oak timber, admirably put together with oak pins; the mouldings all cut out of the solid, and set out upon simple principles; the halving, mortising, tenoning, and framing, performed with the greatest nicety, and no iron work of any kind, not even a nail, used; their pitch varies in most examples, but the loftiest were the earliest built. The greater portion were originally covered with lead, of a weight equivalent to 10 pounds to the foot superficial.

The roofs of some of the early buildings in Brittany, where timber is not abundantly produced, are exceedingly simple in their construction; the principals have the form of a pointed arch, or inverted boat, and are formed on masonry or rubble work: the walls are carried up upon them to the necessary height, and then cut to the rake of the roof. The walls of the houses are brought up to a level, and then quarter circles described determine the commencement of the roof. In many parts of Germany, barns are erected upon this principle, using timbers instead of masonry: fir planks are united in the form of a pointed arch, into which a piece of timber is framed resting upon the top of a plate, mortised on to the head of an upright post: upon this is laid a rafter, which carries a number of purlins to receive the boarded covering. The same system is adopted in Holland to houses of two or more stories; the principals are formed of solid timber, and placed about 12 feet apart; the outer walls are framed together, and the spaces between the timbers filled in with brick; the timbers are painted yellow, the rooms admirably arranged within, forming convenient houses at a moderate cost for people of the working classes.

Tie-beams, at their introduction, completely altered the principles of framing roofs; the ends of the rafters were now held together at the feet, by framing them into a horizontal piece of timber which acted like a rope, and resisted their being pulled asunder, in the direction of its length. When a heavy body is supported by two pieces of timber, A C and B C, its effects depend upon their position; the farther the ends of the timbers are apart, the greater is the strain upon them: the weight resolves itself into two forces, one in the direction of each beam.

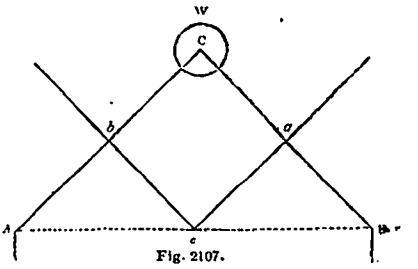


Fig. 2107.

The weight W might be supported upon an upright post in the direction of C*c*, where its vertical force is equal to the weight: this may be resolved again into two forces, acting in the direction of the beams, that would produce the same effect as the vertical force C*c*.

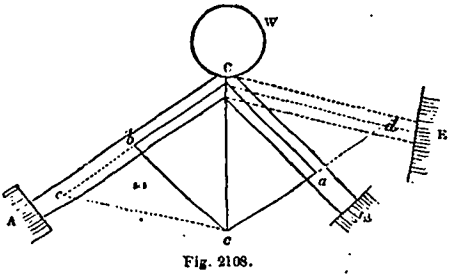


Fig. 2108.

If the vertical line C*c* be drawn through the centre of the weight, and *ac* be drawn parallel to the rafter or beam A C, also *bc* parallel to B C; then the weight and pressures exerted will be found thus:—as the line C*c*, is to the line C*b*, so is the weight W, to the pressure in the direction of the beam A*c*: and as the line C*c*, is to the line C*a*, so is the weight W, to the pressure in the direction of the beam C B.

If the position of the beam were that shown by the dotted lines C E the magnitude of the strain would be considerably increased on both beams: by drawing lines parallel to them in this position, expressing the weight by the line C*c*, then the pressure on the beam, in the position C E, is expressed by the line C*d*, instead of C*a*, and the strain on C A by the line C*e*; we find that considerable strains are often the result of comparatively trifling weights, when a change is made in the position of the supports A, B, and E. By drawing out a variety of diagrams we are enabled to form some idea of the changes which position can effect, and to judge of the alterations in the duties which the several timbers combined into a truss or piece of framing have to perform; the object of the carpenter ought always to be that of not relieving one piece at the expense of another, but of so arranging the whole that the burden may be equally distributed.

An easy method of ascertaining how much each sustains is, by passing a string over two pulleys, as B and C, and tying another to any point at A, which has a weight attached to it at W: if the sum of the weights *b* and *c* be greater than the single weight W, it is a position in which they may be placed, and will allow the three weights to be at rest, or in equilibrio. When the whole is in this state of equilibrium, draw the figure on paper, and from a scale of equal parts make A F equal to the number of pounds contained in the weight W, and continue the line B A to E, and draw the line E F parallel to A C: then F E measured on the scale will express the number of pounds on the weight at *c*; and the length of A E by the same scale will show the number of pounds in the weight *b*. When the three weights are equal, the three lines A F, F E, and A E will be equal, and all the angles round the point A, where the perpendicular string is tied, will be equal. When these three forces are in the same plane, and meet in a point, they are always in equilibrio, and the forces are represented by the three sides of a triangle drawn parallel to the directions of the forces. When a weight is kept at rest by three forces, and any two are represented in magnitude and direction by the two sides of a triangle, the third side, taken in order, will show the magnitude and direction of the other force.

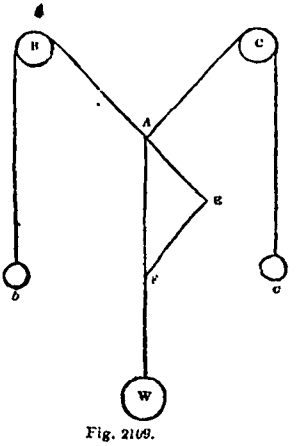


Fig. 2109.

The sides of triangles are as the sines of the opposite angles, and when three forces keep a body in equilibrio, each is proportional to the sine of the angle made by the other two: the weight W, for instance, is as the sine of the angle A F E, the weight *b* as the sine of the angle A E F, &c. &c. When the framing of a roof, or a pair of principals, are drawn upon paper to a scale, the proportion of the forces may be correctly ascertained in this manner, without further calculation, at least sufficiently near for all practical purposes. Tie-beams connecting two rafters at the feet prevent their spreading; and the horizontal strain given to the tie-beam is deposited with the entire weight, and without any thrust upon the walls. The triangle is the strongest form that can be given to framing; suppose three pieces of timber united by pins, such a triangle will not alter its form; but if the top pin be drawn out, the two inclined sides will revolve round the other two pins; but as long as the three pieces of timber are of the same length the figure will retain its form. The pins, upon which any pair are held together, are free to revolve in circles, before the third is put in, but this makes no difference to its strength or its form: from this very simple principle two important rules are elicited for framing timbers, and which show that all framing should have the figure of a triangle, with the largest or most obtuse angle that can be obtained, or that the application will admit of, care being taken to prevent the sides from bending.

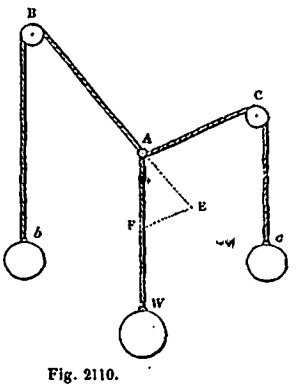


Fig. 2110.

To properly brace a piece of carpentry, so as to resist any force that may be applied to it, and to give it the necessary stability, requires careful arrangement, and considerable knowledge in the art; but the chief object to be attended to in framing a roof is to provide against any alteration in the form of the triangle made by its principals, or the sagging or bending of the tie-beam, which is the longest side of it. In determining the scantlings of the various timbers, it must be borne in mind that the load the roof has to support is equally distributed over their whole surface, and which never need be calculated at more than a floor has to carry. The timbers are, however, more apt to shrink, and alter their form by change of temperature, and oak is more subject to this than fir. The principals of a roof may be regarded as the girders of a floor, the common rafters as the bridging joists, but there is the advantage of giving the principals additional strength by framing and trussing them, which cannot be done so readily with the girder; and the more at right angles to the rafters the strutting pieces are placed, the firmer and stronger the roof becomes.

The most advantageous method of employing a piece of timber, so as to have its entire strength, is to place it perpendicularly, as in a king-post, which not only holds up the tie-beam where it is the weakest and inclined to sag most, but, when properly strutted, forms with the principal rafters a complete truss. A collar in addition to the tie-beam placed half-way up the principals, and acting as a coupling, has not the stability of the king-post with its braces, which transport the weight of the purlin to a point or points which contribute to its strength.

Some of the roofs used between the fifteenth and seventeeth centuries had their principals set out in the form of an equilateral triangle; a collar was framed into them, and on this rested a king-post, into the head of which the tops of the principals were framed and pinned; two short struts were placed above the collar, from the king to the rafters, and two others below the collar were also framed into the principals: on the principals were pinned blocks, to support the purlins without cutting into them, and the common rafters had their feet framed into a small plate, which laid fair with the outside of the wall; they were also securely pinned to the purlins and the ridge piece, which rested on the top of the king-post or tree-post in the middle.

This formed altogether a very solid roof, but required a quantity of timber, and of course a considerable expense: the tie-beams generally, for roofs from 25 to 30 feet span, were in depth equal to an eighteenth part of the width between the walls, and all the rest of the timbers in proportion.

In some early buildings, where it was required to improve the rooms obtained in the roof, the tie-beams, on which the floor rests, are placed two or three feet below the level of the pole-plate, upon which the common rafters pitch: by forming a semicircle over the tie-beam, composed of crooked or cut timbers, and introducing above it another tie framed into the principals, and again strutted on to the ends of the lower tie-beam, a convenient arrangement for a room is obtained: above the upper tie was introduced the tree-post, with a collar and struts, which deposited the weight of the upper portion of the roof on to the tie-beam, supported partly by the middle of the arch.

Mansard's Roof, as it is termed, is curbed, for the purpose of keeping down the height of a building, or obtaining a more capacious apartment within it; the whole is usually arranged within a semicircle, but its system may be said to consist of four pieces or rafters hung together in such a manner that, if inverted, they would naturally assume the form given to them.

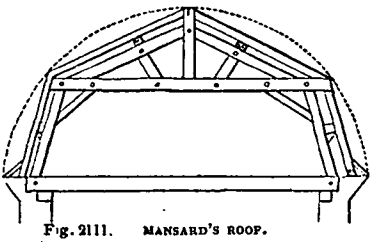


Fig. 2111. MANSARD'S ROOF.

The tie-beam in this case, which holds the wall plates together, are the common joists of the building, and the principals and struts above the collar, which hold in the curb-plates, are proportioned to their uses.

Many granaries and storehouses of considerable extent are constructed in a very simple manner, and have their roofs in a single span: the entire width is divided into four parts, two of which are given to the middle. Upright posts with braces framed into the joists, which extend through the entire width, support the middle of the rafters: as they are equally balanced, they have but little outward thrust.

It is the general practice in England, where the span of the roof exceeds 25 feet, to adopt the king-post and tie-beam, and not omit the struts. Where it is required that the backs of the common should lie even with those of the principal rafters, the purlins must be framed into the side of the latter, or strapped up with iron. When the tie-beam is

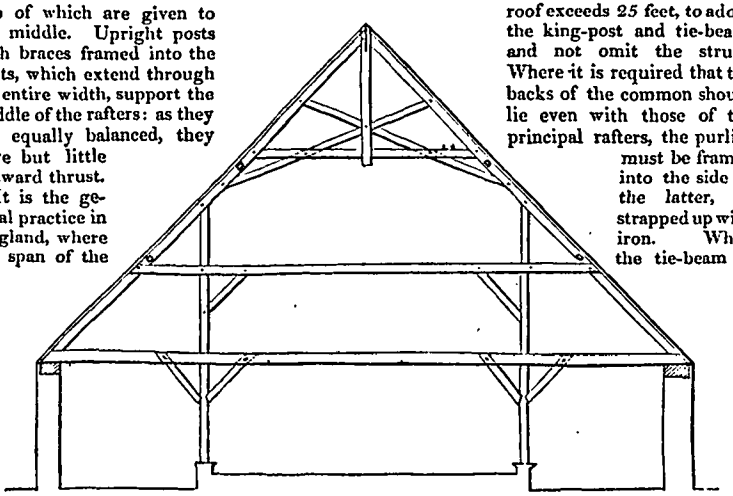


Fig. 2112. SECTION OF A WAREHOUSE.

placed at a height above the level of the plates on which the rafters pitch, it is called a collar: the chief object in framing a roof should be to make it neither too heavy nor too light, though the former is often preferred to the latter, from the idea that weight upon the walls adds to their stability, so long as it is not sufficient to crush them.

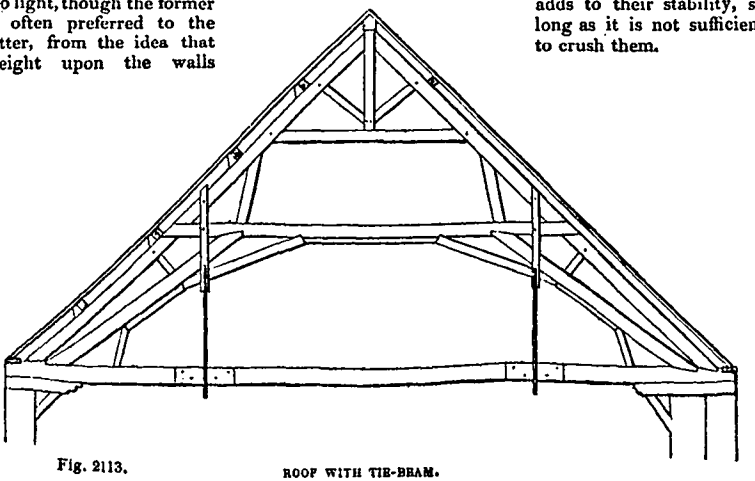


Fig. 2113. ROOF WITH TIE-BEAM.

When the upright posts are omitted, for the sake of obtaining a spacious room, it is necessary to hold up the tie-beams, so that they are prevented from sagging; and where two or more stories are required in a roof, as in theatres, every means must be taken to render them secure.

At the Palais Royal, in Paris, is a remarkable roof of considerable span, with two floors within it: the tie-beams are scarfed together, and hung up to the rafters by strong stirrup-irons.

The roofs of the houses in Flanders are frequently contrived to contain three or more floors, and examples exist of more than double that number: when the building is of a considerable span, and the roof *true pitch*, it is important that the space it contains should not be entirely useless; upright posts and partition walls generally sustain a portion of the load that such an arrangement must produce. In theatres and large assembly rooms, where the whole weight of the roof is laid upon the outer walls, difficulties often occur that require considerable skill on the part of the constructor, to avoid the danger which accompanies them. The first study should be directed to securing the feet of the principal rafters to the ends of the tie-beams, and wherever a joint occurs in the length of the latter to hold it up, and prevent it from sagging: the more securely the timbers are framed together and made to resemble an entire truss, the less is their liability to disarrangement, which often occurs through hanging additional weight to the several floors contrived within it, or the bending or pushing out of the walls of the building.

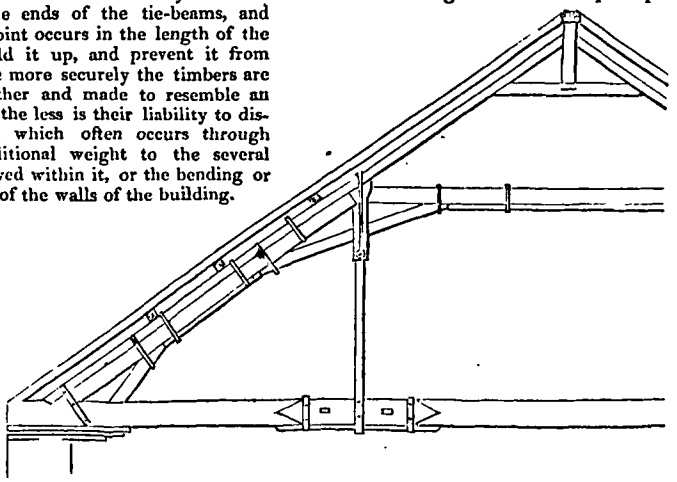


Fig. 2114. ROOF AT THE PALAIS ROYAL.

In some instances, as at Louvois, the great weight of the roof is deposited below the tie-beam by an angular brace, at the foot of which is a tie-beam hung up to pendentives

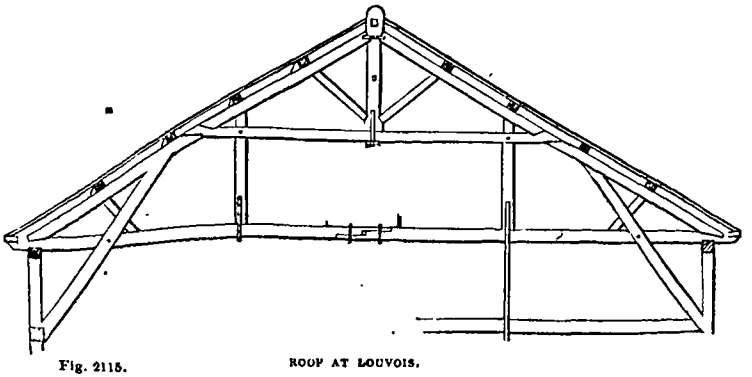


Fig. 2115. ROOF AT LOUVOIS.

attached to the principal rafters, where the collar that supports the king-post is framed in: another iron strap secures the collar to the post, and binds all firmly together.

Several methods have been adopted to brace the rafters together where tie-beams have not the king-post to hold them up: in some examples, on one side is a stirrup-iron, and on the other a brace; the latter is rather calculated to deposit weight than to uphold it, whilst the former, which performs both services, is to be preferred.

The carpenter should avoid as much as possible the effect of all cross strains, or those which are transverse; and in the arrangement of the timbers of a roof, he should never employ a very open angle at a point where a load is to be supported, the obliquity of the two pieces forming the angle requiring them to exert a great force, in order to oppose a much smaller one.

If the two braces forming the obtuse angle in the present figure consisted of wood cut across the grain, and the piece joining their extremities were cut in the usual manner, the oblique pieces would contract more than the others in drying, and the angle would become more obtuse, so that the strain would be increased considerably beyond what it was at first.

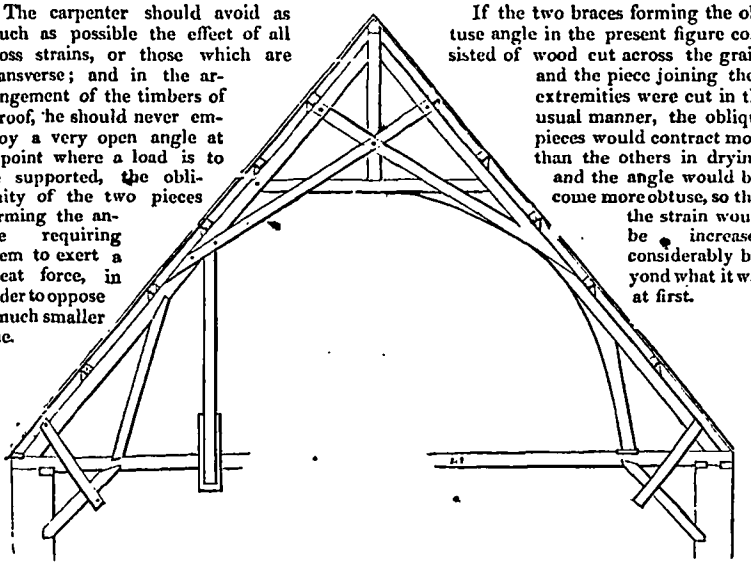
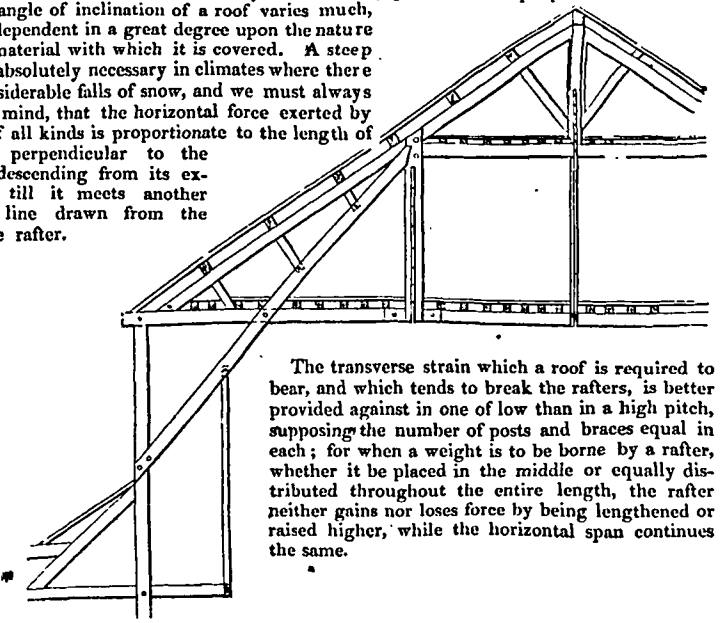


Fig. 2116. ROOFS WITH TIE-BEAMS SUSPENDED.

At the Theatre of St. Martin, at Paris, which is of considerable span, the timbers are arranged for the convenience of the scenes, which are in many instances suspended from it; shores or supports are consequently necessary to discharge or bear the great weight to which the several floors are subject, and they are admirably placed for the purpose.

The angle of inclination of a roof varies much, and is dependent in a great degree upon the nature of the material with which it is covered. A steep roof is absolutely necessary in climates where there are considerable falls of snow, and we must always bear in mind, that the horizontal force exerted by roofs of all kinds is proportionate to the length of a line perpendicular to the rafter, descending from its extremity till it meets another similar line drawn from the opposite rafter.



The transverse strain which a roof is required to bear, and which tends to break the rafters, is better provided against in one of low than in a high pitch, supposing the number of posts and braces equal in each; for when a weight is to be borne by a rafter, whether it be placed in the middle or equally distributed throughout the entire length, the rafter neither gains nor loses force by being lengthened or raised higher, while the horizontal span continues the same.

Fig. 2117. THEATRE OF ST. MARTIN.

In the Palais Royal, at Paris, over the larger apartments the several floors are all hung by irons to the principal rafters, which are so strutted and braced that they effectually

resist the strain to which they are subjected: the feet of the main timbers are secured by iron straps, and from the outer walls are projecting corbels, to afford a firm rest to the joists and braces which are framed into them.

The obliquity given to a rafter lessens the effect of the weight which it bears, precisely in the same ratio that its length diminishes its strength: for in all beams, when lengthened, there is an additional weight to be supported, which diminishes their strength, and in calculating that of rafters, we must remember that the slight flexure produced by the transverse strain diminishes their strength by resisting a longitudinal force.

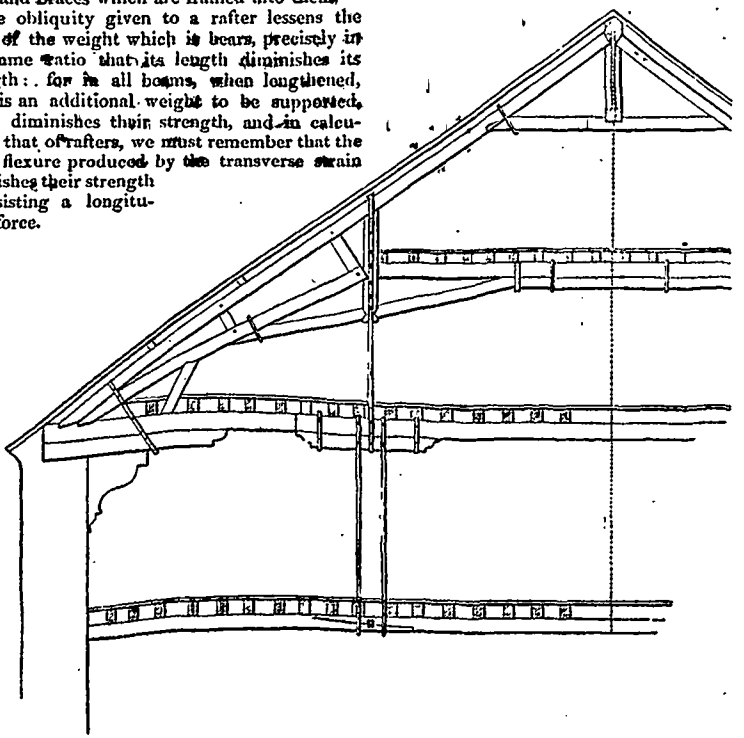


Fig. 2118. ROOF AT THE PALAIS ROYAL.

In framing the feet of the principals into the tie-beam, care should be taken to place them at some little distance from its extremities, at the same time not allowing them to be projected a long way within the walls, which might occasion the bending of the tie-beam, an evil which often occurs when the slant of the roof is very flat; in many of our churches covered with lead, this portion of the construction is very faulty. Every roof, however well put together, must undergo some change from its original form, from the shrinking of the timbers, but a scientific knowledge of this fact will sometimes prevent any great evil from arising; to know how much a piece of timber will yield when compressed will enable us to give it such dimensions that its form will be retained, and its efficiency continued: when any part of a roof assists in suspending the floors below, it becomes important to consider the nature of this new strain, and to provide properly for it. In the present example, the upper floor forms a portion of a trussed arch, which assists in carrying the principal rafter at the point where the suspension rods are attached, and as long as the feet of the rafters are maintained in their place, there is perfect security, provided also that the tie-beams are not drawn asunder, which hold in the wall plates and corbel timbers beneath them. A truss of this description will bear great weight, as it forms but one piece of framing, the timbers of which cannot pull out, each being acted upon in the manner of a strut, and if of a dimension to resist bending, there is no danger of the whole retaining its strength and usefulness.

Iron rods are now often substituted for king-posts, and all other situations where beams perform the office of ties, and it is advisable to introduce iron sockets whenever it is possible, to receive the ends of all braces and struts, so that the principal timbers may not be weakened by cutting mortises or notches to receive them. The principal rafters may be set in an iron shoe, which may be bolted down upon the tie-beam, and every purpose of a mortise answered without the labour of cutting it or destroying the strength of tie-beam. Although iron is twelve times heavier than fir timber, it is more than twelve times stronger, therefore

both equal in weight and strength, when properly proportioned. Roofs which are dependent upon the principle of a truss and straight tie-beam should have all their timbers proportioned to the duties they perform, and few subjects deserve more attention, as it seldom happens, that in large buildings we can place the several timbers exactly where the strength of the roof requires them.

The Theatre at Bordeaux has a fine example of roof, which is adapted to all the purposes required for the arrangement of the scenes: the whole, strutted and braced in a judicious manner, is partly curbed, and the plate, where the bend is made, is secured by a piece of timber bolted to the tie-beam.

A curb roof is sometimes preferred, both on account of a greater space being contained within it than a plain roof of the same height, and of its exerting less strain on the tie-beam or abutments: the carpenters of the middle ages thoroughly understood the mechanical principles by which the equilibrium of a roof could be maintained, and the examples they have left us are deserving of our particular attention and study.

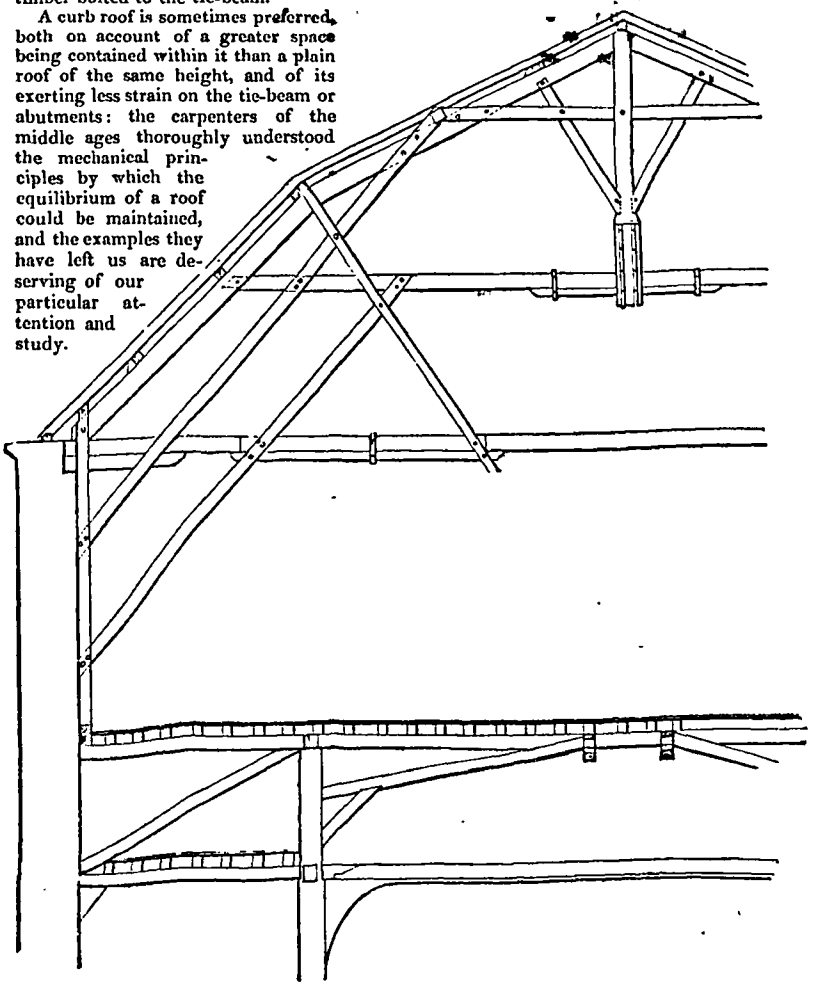


Fig. 2119. THEATRE AT BORDEAUX.

Roofs of theatres, or any building where the opening is too wide to be spanned with one or even two pieces of timber, are generally framed by a combination of pieces, which in some degree assume the property of an arch constructed in masonry, but their principles of stability differ: all carpenter's work is dependent upon the strength of the material and manner in which it is framed or put together. When timber is strained by a force that destroys the balance existing throughout its parts, that strain should be examined, and it should be decided whether it is produced by stretching or compressing: in all framing there will be one point in a neutral state, as in a solid piece of timber.

At the Palais of Versailles is a roof of novel construction, which has two collars, resting upon two upright posts on each side, to allow of a passage between them.

Theatres admit of such an arrangement, the space between the two upright posts on each side the roof being usually devoted to the passage which conducts to the several boxes in front of the interior part. The ceiling of the pit is suspended to a king-post, strengthened on each side by a long strut that braces the whole together.

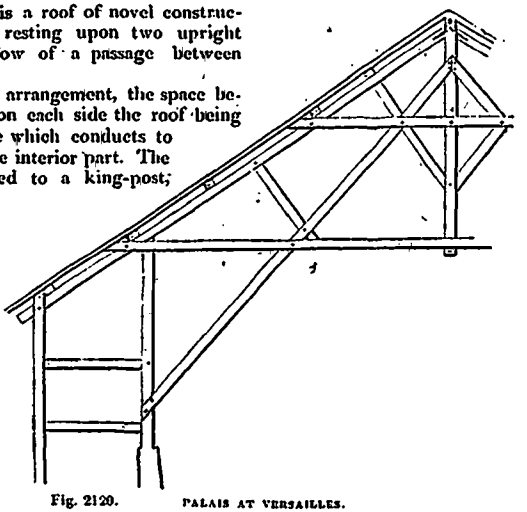


Fig. 2120. PALAIS AT VERSAILLES.

At the Italian Theatre at Paris, the roof was formed by a double arrangement of prineipal rafters, so strutted and braced as to have strength enough to hold up the floor by means of iron rods, which covered the entire width of the theatre.

When roofs are constructed in this manner additional strength would be obtained by the introduction of a St. Andrew's cross between each pair of upright struts, framed between the upper and lower principal rafter; these bolted together would form a strong truss, and support or hold up a considerable weight; the abutments require to be held firmly in their position, and in the present example the lower strut was introduced to discharge a portion of the weight upon the floor below, where the outer walls are tied together. The collar or beam under the king-post also acts as a strut, to prevent the sagging of the truss into which it is framed.

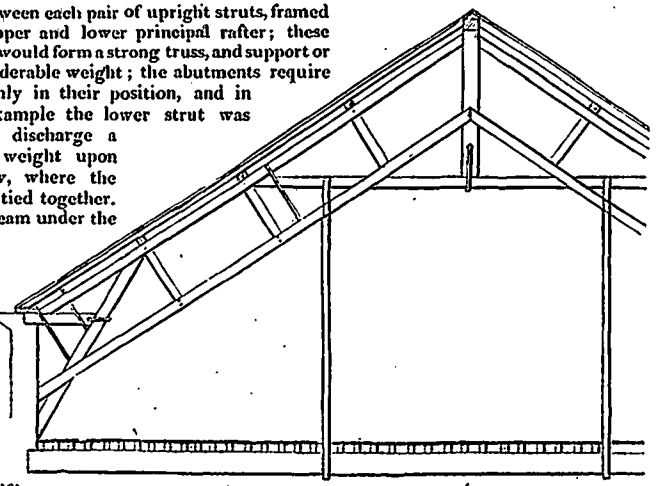


Fig. 2121. THEATRE DES ITALIENS, AT PARIS.

Roofs without tie-beams are frequently used where height is required in the building they cover, but, with all the care possible, it is difficult to frame them so that they will

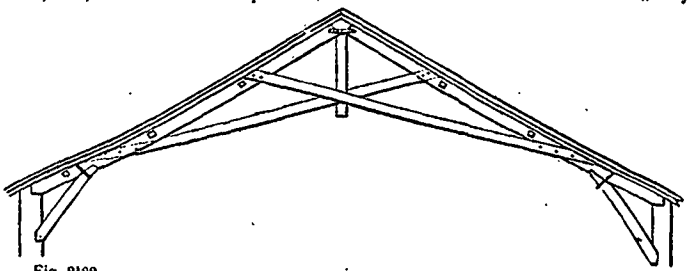


Fig. 2122. ST. MARTIN'S, PARIS.

resist depression, or to hold their form sufficiently to maintain the outer walls erect; the shrinking of the timbers is another cause of change.

Over an assembly room at Brussels, the coved ceiling was carried up to the under side of the rafters, and scarcely any space was lost; the abutments were produced by the aisle formed by the columns on each side, which were strutted above, so as to insure perfect stability.

In roofs of this description the framing might be so equally balanced upon the upright post, that there would be little or no disposition to thrust out the external walls: such construction has been adopted by the builders of small houses in the neighbourhood of London, who have balanced their rafters upon the two internal partitions of the house, which

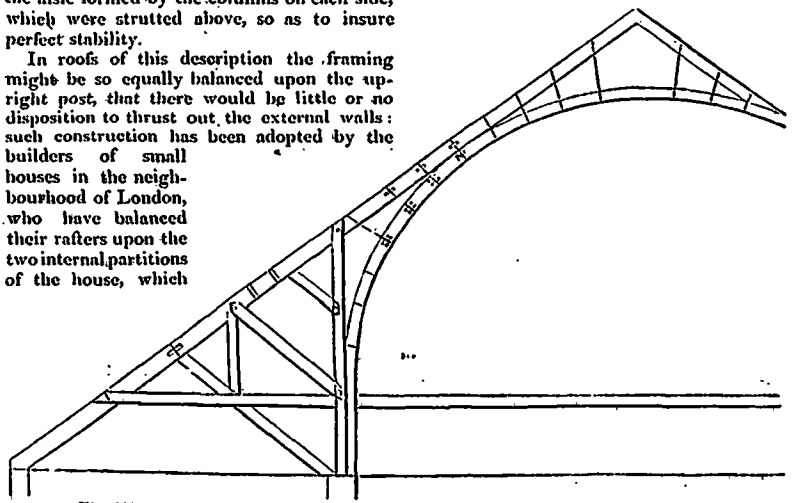


Fig. 2123. ROOF AT THE BALL ROOM AT BRUSSELS.

have enabled them to carry up the outer walls a few feet in height above the upper floor, and thus gain more head-way in the attic than could be obtained if the rafters were framed into a tie-beam in the ordinary manner: but the construction is faulty, and ought not to be adopted, as it is liable to push out the outer walls, if not very accurately executed.

A similar principle to that in fig. 2123. was adopted by Sir Christopher Wren, and has been followed by several architects since his time: buildings divided into four equal parts, two of which are given to the centre, may have this roof applied with great advantage; the coved ceiling being extended to the very summit, every part of the space comprised beneath the rafters is available. The circular ribs, formed of several thicknesses of plank, are strapped to the principal rafter, and abut against the upright posts, which carry the weight of the roof.

The Roof over the Pantheon, or St. Genevieve, at Paris, is contrived to permit the curvature of the vault to rise above its springing: another roof in the same building is differently framed, and has a considerable quantity of timber bestowed upon its arrangement, which is remarkable for its strength.

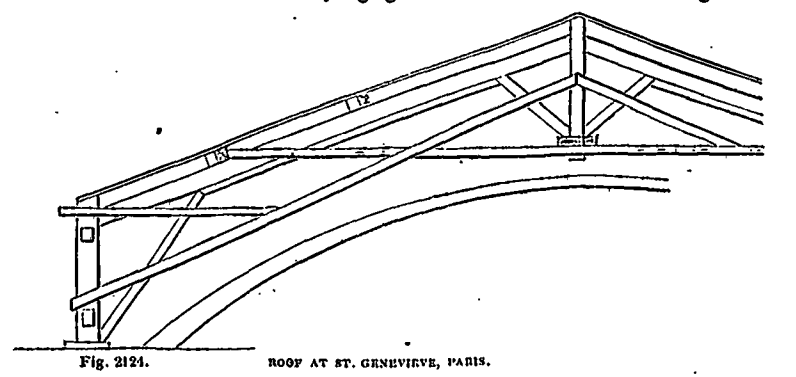


Fig. 2124. ROOF AT ST. GENEVIEVE, PARIS.

The two side walls are tied together by strong oak plates; over that on the inside is an upright post, strutted on each side to the principal rafter: a collar framed above the struts prevents the posts from being forced out of their perpendicular position, and an iron bolt

holds up the collar, in the middle of its length, to the king-post; a brace parallel to the principal rafters unites the several portions of the framing together: three purlins on each side support the common rafters, forming a roof that could be lifted off in one entire piece.

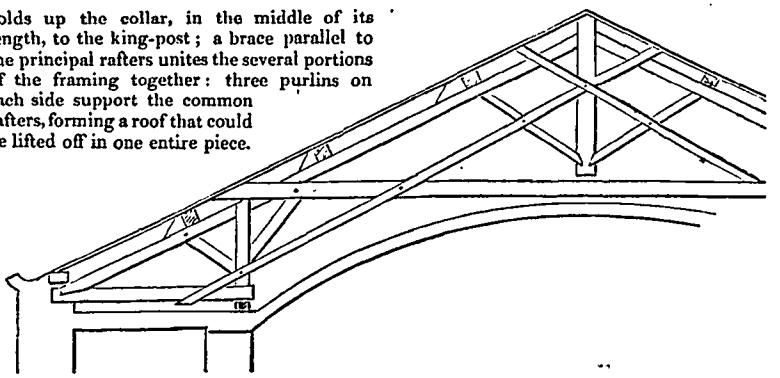


Fig. 2125. ROOF AT ST. GENEVIEVE, PARIS.

At the Opera des Arts, at Paris, over the proscenium, it was necessary to have a lofty and spacious room for the purpose of mounting the scenes and other useful purposes; this is admirably contrived, and the principal timbers of the roof are so framed as to resist any effects they might be subject to when heavy weights were suspended from them.

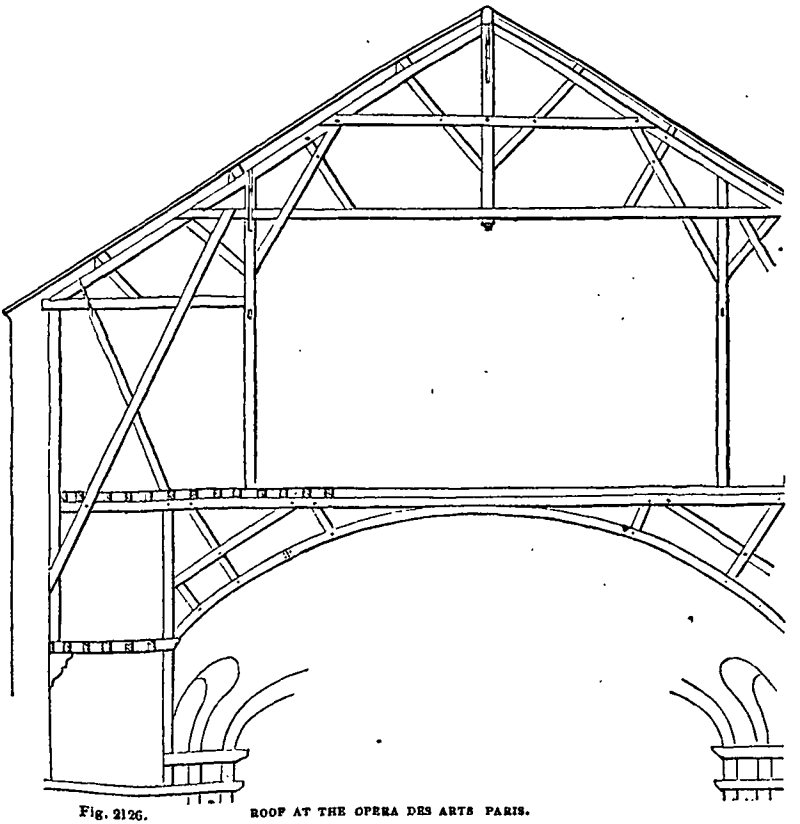


Fig. 2126. ROOF AT THE OPERA DES ARTS PARIS.

Roofs framed with pieces of timber which act as struts as well as braces are both simple and strong in their arrangement.

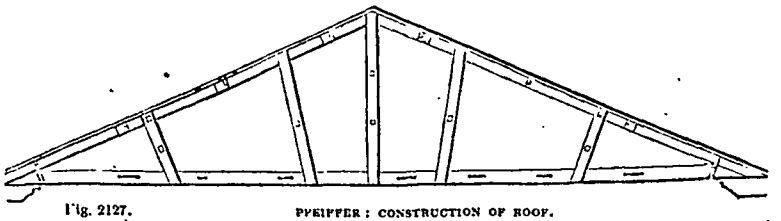


Fig. 2127. PFEIFFER: CONSTRUCTION OF ROOF.

Pfeiffer executed several roofs in Germany, which derive considerable strength from the introduction of inclined timbers, which serve the double purpose of holding up the tie-beam to the principal rafter, and strutting them: where timbers act as struts and ties an iron bolt is almost indispensable to secure the joints; but as the carpenters of the middle ages seldom introduced iron into their framing, they were obliged to form their joints in such a manner as to answer the same purpose; the shoulders of the timbers were accurately cut, to fit both the principal and tie-beam, into which they were framed and secured by an oak pin; as long as the latter resisted fracture or drawing down, the framing remained entire, and from the observations made upon several ancient roofs so constructed we rarely find that any injury has taken place.

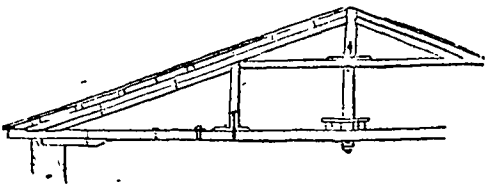


Fig. 2128. ROOF AT ST. PAUL, ROME.

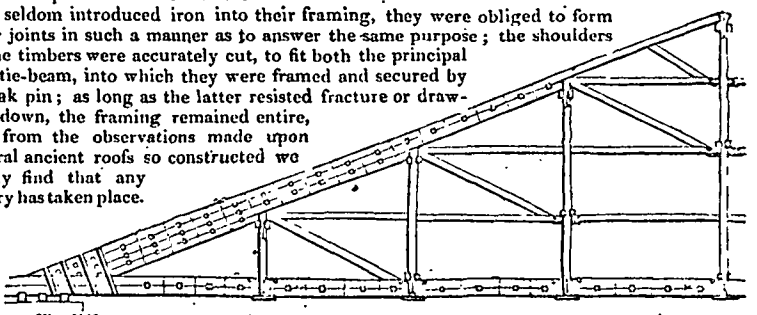


Fig. 2129. ROOF AT RIDING-SCHOOL, MOSCOW, AS IT IS AT PRESENT.

The celebrated roof of St. Paul's-out-of-the-walls at Rome exhibited an admirable construction, and was perhaps one of the earliest where the upholding the tie-beams by iron rods was introduced.

The riding-house at Moscow, which at present exists, covers a considerable area; it is framed in an admirable manner, upon the same principles; a series of ties and struts in succession are united into one simple and complete truss.

King Post Roofs, or their principle, we find adopted very early in Italy, and particularly in the basilicas at Rome: in the church of St. Paul-without-the-walls, where the span is nearly 79 feet, was a finely constructed roof destroyed by fire a few years ago: it was constructed of fir timber, and consisted of pairs of trusses, placed 15 inches apart, and each pair rested on the walls, with a distance of 10 feet 6 inches between them. The manner in which the trusses were framed together was as simple as it was ingenious, and a remarkably strong roof was formed by it: a king-post received the upper ends of the principal rafters, which were about 22 inches by 15; a collar or straining piece 15 by 12 abutted against the heads of two queen-posts, the position of which was maintained by additional timbers, placed under the principals, and forming a double thickness where the greatest strength was required.

The Tie-beams were formed by scarfing two lengths of timber together, and securely strapping them with three stout irons; their scantling was 23 inches by 15.

The Collar, or upper tie-beam, was placed at two-thirds the height of the king-post, and by the introduction of the pairs of queens the tie-beam was hung up in three places to prevent its sagging; such a suspension of the tie-beam by the middle, and again at 14 feet on each side of it, exhibits a thorough knowledge of the true rules which should direct the carpenters: no tie-beam should exceed the length of 15 feet, without some precautions similar to these being adopted, to prevent it from drawing in the wall plates and crippling the truss. In this example we have an early instance of suspending the tie by means of the heads of a king and a pair of queens, and which is now universally adopted, though the irons which have been used for the purpose have been variously formed; sometimes bolts and at others stirrup-irons secured by keys have served the purpose.

The simple King-post Truss is usually adopted in buildings where the span does not exceed 30 feet, and the rise given to it varies as the inclination of the rafters are formed to receive different kinds of covering: for thatched buildings the height is made equal to half the span; for pantiles two-ninths; plain tiles two-sevenths, and for slate one quarter, a quarter of the span forming an inclination of angle of 26½°.

The king-post suspends as well as supports, and must be proportioned according to the span; its scantling may be found by multiplying the length of the post in feet by the span

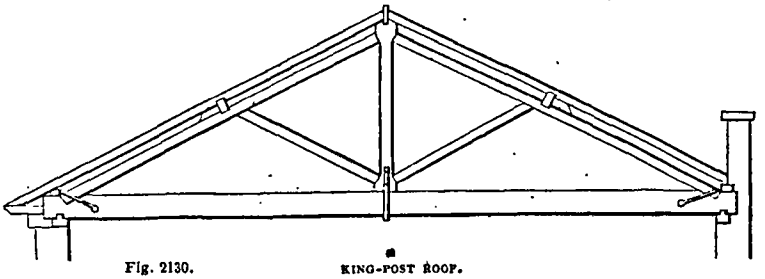


Fig. 2130. KING-POST ROOF.

in feet, and again their product by 0·12 for fir and by 0·13 for oak, which latter product will be the sectional area of the king-post in inches; by dividing this area by the breadth, or by the thickness, either may be obtained; the area divided by breadth gives thickness, and divided by thickness gives breadth.

Tie-beams have two strains, one in the direction of their length, and the other from the weight of the ceiling, or whatever is suspended from it: the thrust of the rafters is never so great as to pull the beam asunder, and the chief strain which the tie-beam is subjected to, and which is to be guarded against, is the weight of the ceiling, or any thing which induces it to sag in the middle, or any other part of its length. The weight it carries will be proportional to the length which is unsupported: where a ceiling has to be supported, the scantling of the tie-beams is found by dividing the length of the longest unsupported part, by the cube root of the breadth, and then multiplying the quotient by 1·47 for the depth of fir in inches, and by 1·52 for that of oak: where rooms or warehouse floors are held up or supported, then their strength must be provided for in the same way as for girders. To find the scantling for the principal rafters, where the king-post is in the middle, multiply the square of its length by the span in feet, and divide the product by the cube of the thickness in inches: for fir, multiply the quotient by 0·96, which will give the depth in inches.

Struts and Braces must be proportioned to the effect they have depending upon them, or upon the load they are to carry; when they are placed at the back of the principal, in a right angle, or perpendicular to its inclination, the strain upon them is the least, and when the same inclination is given them as to the roof, the same strain is thrown on the principal as is borne by the strut. By multiplying the square root of the length supported in feet, by the length of the strut in feet, and then multiplying the square root of the product by 0·8 for fir, the depth may be obtained, which multiplied by 0·6 will give its breadth in inches.

Common Rafters, being uniformly loaded, they are usually made 2 or 2½ inches in thickness, and their depth is found by dividing the length of bearing in feet by the cube root of the breadth in inches, and multiplying the quotient by 0·72 for fir or 0·74 for oak, to obtain the depth in inches.

Purlins must have their scantling proportioned to the distance the principals are apart, and as the weight diffused over them is uniform, the stiffness is reciprocally as the cube of the length. By multiplying the cube of their length in feet, by their length of bearing in feet, the fourth root of the product will be the depth in inches for fir; or, multiplying by 1·04, will give the depth for oak: this multiplied by 0·6 will give the breadth. Purlins should never be framed into the principal rafters, which are weakened by having mortises cut into them; it is better to lay them on the principals, and simply notch down and secure them; when the purlins are weak, the roof is materially damaged, proper strength being of the highest importance to them.

When king-post roofs are adopted, the following scantlings for the chief timbers may be adopted.

Span.	Tie-beam.	King-posts.	Principals.	Struts.
Feet.	in. in.	in. in.	in. in.	in. in.
20	9 by 4	4 by 4	4 by 4	4 by 3
25	10 by 5	5 by 5	5 by 4	5 by 3
30	11 by 6	6 by 6	6 by 4	6 by 3

Queen Post Trusses have two suspending pieces, and are used when the span is above 30 feet up to 45 feet; there is an advantage in this species of framing which is not obtained where the king-post is introduced, viz. a passage or space available for many useful purposes: where queen-posts are used each is so placed that it bears one-half the span: to find the scantling of one of these suspending pieces of timber, multiply its length in feet by the length of the tie-beam it holds up in feet; and then multiply the product so found by 0·7 for fir and 0·32 for oak, to obtain the sectional area in inches of the post:

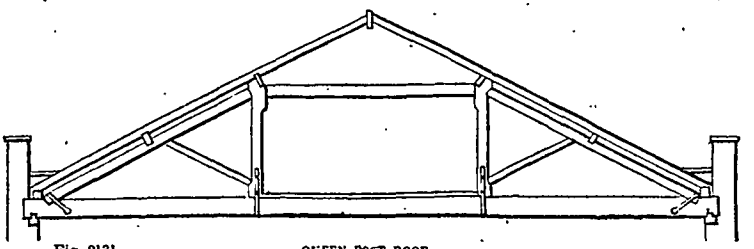


Fig. 2131. QUEEN POST ROOF.

dividing this area by the thickness in inches, the breadth will be obtained: these rules apply to the smaller portions of the posts; the heads must be made as small in addition as possible, as there is then less inconvenience from their shrinking. Carpenters are generally not disposed to use much iron for their trusses, and to dispense as much as possible with straps and stirrup-irons: the most ancient method adopted was to wedge them up, and where oak was employed, and that well seasoned, it seems fully to have answered the purpose. The straining pieces between the heads of the queens, in order that its strength may be as great as possible, its depth should be to its thickness as 10 to 7: by mul-

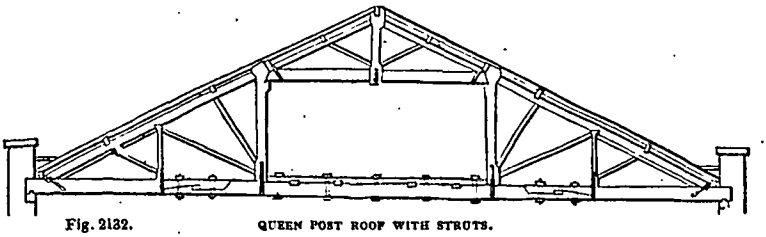


Fig. 2132. QUEEN POST ROOF WITH STRUTS.

tiplying the square root of the span in feet by the length of the straining piece in feet, and then extracting the square root of the product, and multiplying it by 0·9 for fir, the depth in inches may be found: to find the thickness, multiply the depth by 0·7.

The Roof of the Teatro Argentino, at Rome, has a span of about 80 feet, and its slope is about 24°: a short king-post without any side braces receives the upper ends of the principals, and by means of an iron suspends or holds up a collar beneath it, which abuts and frames into the heads of two queens: by this arrangement the tie-beam, which is formed of three pieces of timber, is held up at four places. The whole roof is of fir, and admirably executed. The heads of the queens are strutted on to the ends of the tie-beams, which rest on other timbers laid like corbels on the walls; the whole is sufficiently strong to hold up any scenes that are required to be suspended to them: there are twelve purlins, which carry the common rafters on each side, and the covering is tile, of considerable weight.

The Roof of the Odeon is of oak, and similar in design to the above: its span is about 78 feet, and its angle about 34°, so that the stirrup-irons which hold up the tie-beams are considerably longer.

The scantling for the principal timbers of queen-post roofs may be thus stated: —

Span.	Tie-beams.	Queens.	Principals.	Struts.	Straining piece.
Feet.	in. in.	in. in.	in. in.	in. in.	in. in.
35	11 by 4	4 by 4	5 by 4	4 by 2	7 by 4
40	12 by 5	5 by 5	5 by 5	5 by 2½	7 by 5
45	13 by 6	6 by 6	6 by 5	5 by 3	7 by 6
50	13 by 8	8 by 8	8 by 6	5 by 3	9 by 9
55	14 by 9	9 by 8	8 by 7	5½ by 3	10 by 6
60	15 by 10	10 by 8	8 by 8	6 by 3	11 by 6

Purlins of 6 feet bearing may be 6 inches by 4; of 8 feet, 7 inches by 8; of 10 feet, 8 inches by 6; and of 12 feet, 9 inches by 7: where the common rafters have a bearing of 8 feet, they may be made 4 inches by 2½; 10 feet, 5 inches by 2½; 12 feet, 10 inches by 2½.

Roof of St. James's Church, Piccadilly, is admirably contrived, and is one of Sir Christopher Wren's best designs for a covering to a church or large building where tie-beams cannot be introduced. The breadth of the church is 63 feet, which is divided into five equal parts, three of which are given to the nave, the others to the side aisles. The principal rafters are framed into a plate which rests on the outer wall, and on the capitals of the columns an upright post, immediately over the capitals, supports the principal at about one-third of its length, and a semicircular arch simply cradled is placed between these upright posts, and abuts against them: above this arch the principal rafters are held together by stout collars; the timber framing or the principals is prevented sliding by the St. Andrew's cross introduced over the side aisles. Sir Christopher Wren describes this roof as the cheapest he could invent; it is both convenient and beautiful in its application and arrangement, and it is astonishing that it is not more generally adopted: over the side aisle galleries between every pair of principals are semicircular arches at right angles with the main arch, which rest upon the returned entablatures, so that no portion of this roof is hidden or unemployed. The length of this church is 84 feet, the breadth 63, and height at the centre of the vaulting 42: with its galleries it will contain upwards of 2000 persons.

Roofs trussed with Iron Rods. — Over the passengers' shed at the Croydon railway station, London Bridge, is an ingeniously constructed roof, 54 feet span, formed by a series of struts and iron rods, placed 4 feet apart: the tie-beams camber about 6 inches, and are 12 by 6 inches; the principals are 9 by 6; the struts 6 by 4, and the purlins, which have a 12 feet

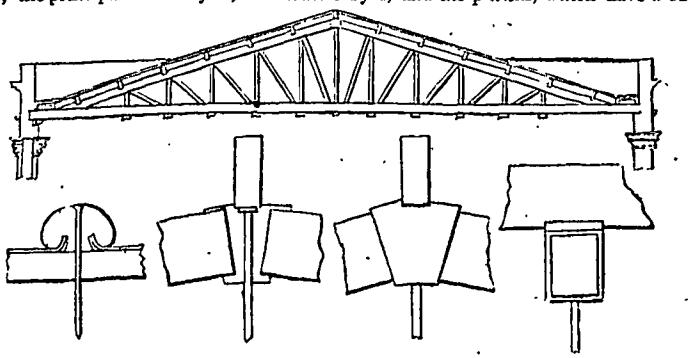


Fig. 2133. CROYDON RAILWAY ROOF.

bearing, are 8 by 3; 1¼ inch boarding with a zinc covering lays upon the purlins without the aid of common rafters: the iron rods or bolts are 1¼ inch in diameter; that which forms the centre or king passes through the ridge piece, against which the two principals abut; there is great stiffness and economy in this system of construction, and the whole has a light effect, and it is evident that the more at right angles to the inclination of the principals the wooden struts are placed, the greater will be the strength.

The Roof of the Hall of Christ's Hospital, London, constructed by Mr. Shaw out of Baltic timber, possesses considerable strength: the walls, 3 feet 6 inches thick, are 15 feet apart in the clear; the rise of the roof in the centre, from the under side of the tie-beam to the top of the principals, is 9 feet 4 inches; it is queen-post trussed, and the tie-beams are held up at five different points, or at every 8 feet 6 inches; the principals are distant from each other 17 feet; the length of the hall is 187 feet, and the breadth 51: every precaution has here been taken to unite the feet of the principals with the ends of the tie-beam, and their weight at the ends is partly borne by iron standards, which rest on shoes worked into the wall below. The principals taper, and are 12 inches by 9 inches at the feet, and 9 inches by 9 inches at the top; the tie-beams are 14 inches by 14 inches; the straining piece between the heads of the queens, 12 inches by 9 inches; the struts 6 inches by 6 inches: between each pair of principals is a pair of main rafters, supported by five longitudinal trusses, and which are also made to carry the ceiling-joists. These longitudinal trusses bear upon the principal tie-beams, which are 17 feet apart from centre to centre; the middle longitudinal truss comes under the ridge, and is very strongly braced; the lower beam is 12 inches by 7 inches, the king-post 6 inches by 6 inches, and head 12 inches by 6 inches; the struts 6 inches by 6 inches: into the head of the kings are lodged the main rafters, which are 7 inches by 5 inches; on these are laid the common rafters longitudinally to receive the boarding, which is laid in the direction of the slope of the roof; so that the lead which covers it is not so subject to derangement as when the

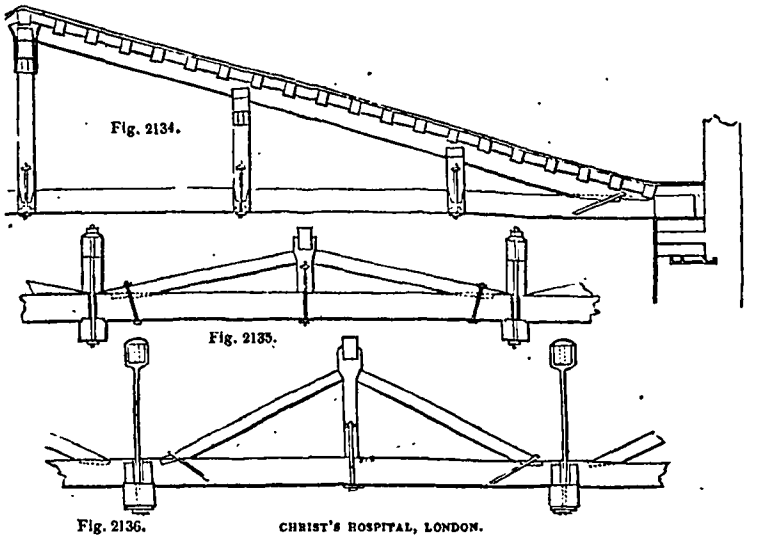


Fig. 2134.

Fig. 2135.

Fig. 2136. CHRIST'S HOSPITAL, LONDON.

boarding is laid the reverse way. The two other trusses on each side are similarly framed, the heights being varied to suit the top of the roof: that of the pairs on each side of the centre is 5 feet from the under side beam to the under side the main rafter; the outside pair are only 2 feet 9 inches in height from the same points.

Pantheon, Oxford Street, constructed from the designs of Mr. Sidney Smirke, exhibits some novelty in the roof, which is admirably adapted for its purpose; it is formed of teak and fir: the centre opening, or the width between the pillars, is 37 feet 3 inches; the pillars are in thickness 2 feet 1 inch, and the side rooms in the clear 23 feet 5 inches, so that the clear space between the walls is 88 feet 3 inches: a semicircular rib, formed of three thicknesses bolted together, and having iron abutments, spans the centre: the middle rib is of teak, 5

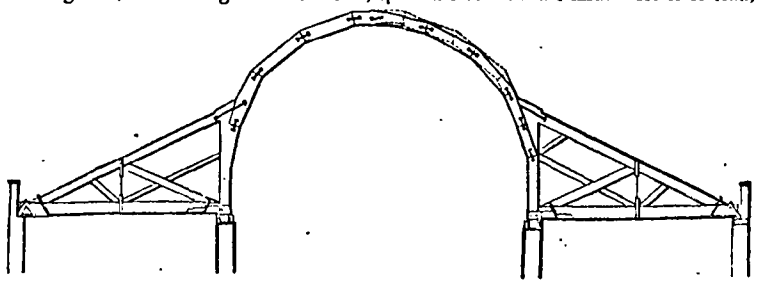


Fig. 2137. PANTHEON, LONDON.

inches thick; the other or side flitches are fir, each 2½ inches thick, and their depth in the smallest part 16 inches: the under side of these is scribed to the curve of the roof; the top is left polygonally, so that the abutting ends of each piece is broader than in the middle; cast-iron shoes receive the feet of each rib, and the three thicknesses are bolted together at the ends.

These nine semicircular ribs, when they rest on the pillars, are framed into upright timbers, which form king-posts to half trusses; these half trusses assist in opposing the lateral thrust of the semicircular ribs, as well as carry the roofs and ceilings of the side galleries.

The tie-beams are 14 inches by 6½ inches; the principals taper, being at bottom 13 inches by 6½ inches, and at top 11 inches by 6½ inches; the large strut is 11 inches by 6½ inches, and the smaller 9 inches by 6½ inches, and 7 inches by 6½ inches: a cast-iron shoe, resting on a stone template, receives their ends where they rest upon the wall, which it is calculated would be of service, should the ends of the timbers at any time decay. At the other end, where the king-post unites with the tie-beam, is a cast-iron shoe, with sockets and flanges, made to unite by means of a longitudinal iron plate, at the head of the main pillars, which are also of iron: the lateral compression of the timbers is provided for by the introduction of iron shoes.

The intermediate ribs, between the iron pillars, rest also on iron shoes, fitted on to the heads of upright pieces, which rest on the centre of the longitudinal plate, which is in two thicknesses, 12 inches by 12 inches, and has a bearing of 22 feet. The principals which form the truss are 12 inches by 9 inches, and they rise 7 feet 8 inches: thus the entire weight of these intermediate ribs is thrown by means of this simple truss on to the main pillars. The roofs over the galleries are covered with slate, the other part with copper, laid on diagonal boarding supported by longitudinal rafters notched on the great ribs.

For roofs of considerable span an arrangement of horizontal and vertical iron ties has been successfully employed; and timber, as in the present example, when framed with care

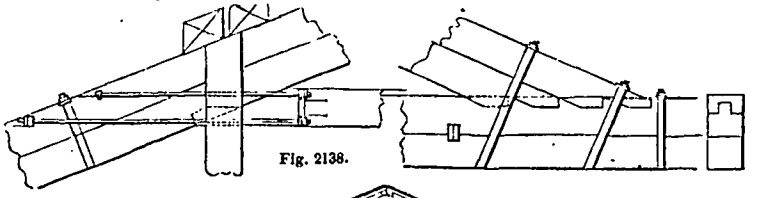


Fig. 2138.

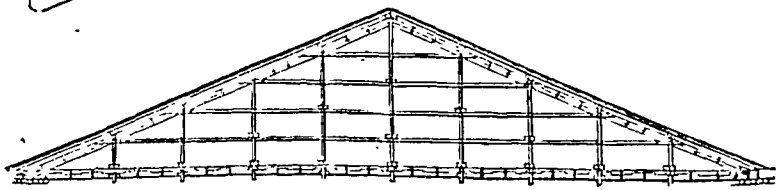


Fig. 2139.

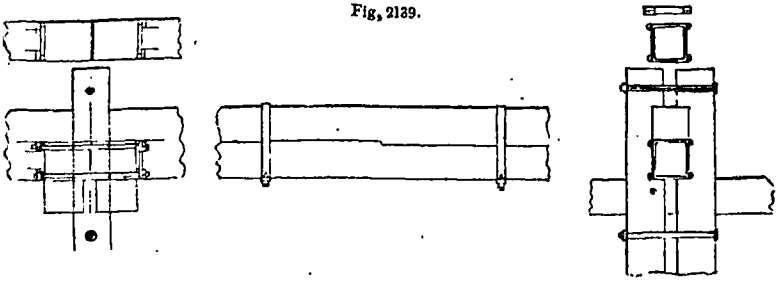


Fig. 2140. ROOFS WITH HORIZONTAL TIES.

answers the same purpose, and is not so costly; each horizontal timber becomes a strut and a tie, and should be placed perpendicularly to perform the same office.

Roofs with iron ties are now commonly preferred for manufactories: at the Butterley

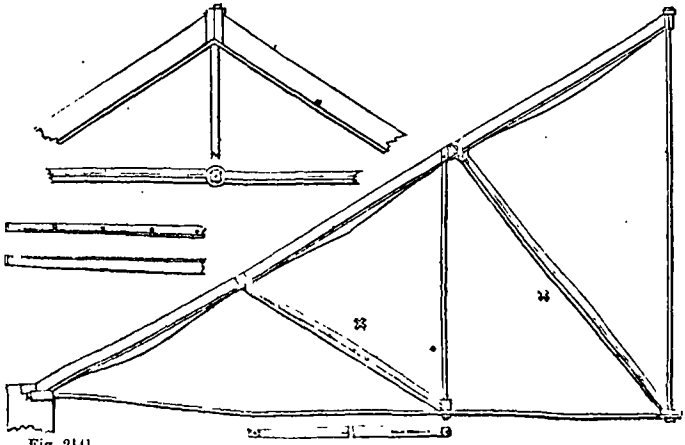


Fig. 2141. BUTTERLEY IRON WORKS.

iron works, they are executed with great strength, lightness, and economy of metal: the small vertical and horizontal rods acting as ties are made of wrought-iron, and the principal rafters and struts, which incline at the same angle, are of cast-iron; such a series of triangles may be extended over roofs of almost any span, if due allowance be always made for the expansion and contraction of the metal.

Fig. 2142. is a design for a roof, in which iron and timber are combined: the vertical rods suspend the tie-beam, and when tightly screwed up bring the ends of the struts home against

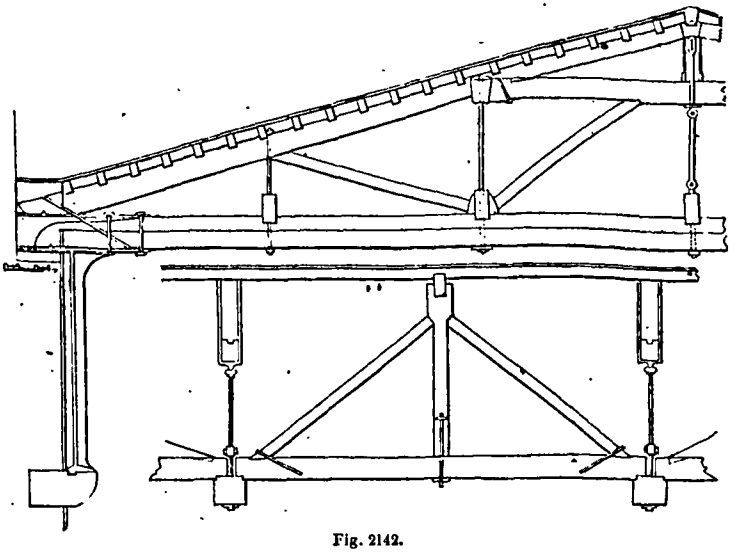


Fig. 2142.

the principals and tie-beam, forming a very strong truss; the purlins may be supported by a truss similar to that in the under side of the figure, by which means the entire roof will be braced in every direction.

Roof of the old Riding-house at Moscow. — The Emperor Paul, whilst travelling through Europe in the year 1781, saw at Darmstadt an extensive riding-house, and on his arrival at Moscow he commissioned his engineers to construct a similar building. Rondelet, upon

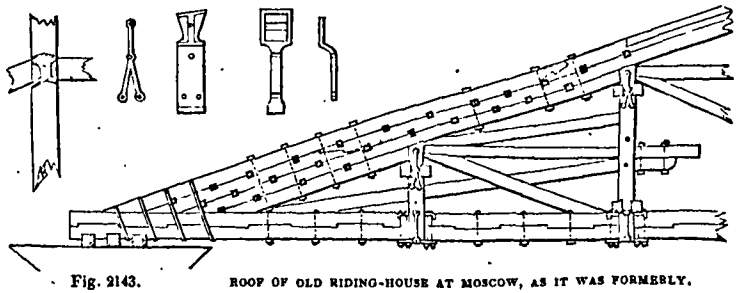


Fig. 2143. ROOF OF OLD RIDING-HOUSE AT MOSCOW, AS IT WAS FORMERLY.

the authority of Kraft, has given the design for a building 1800 feet in length and 290 feet in width, the interior being 220 feet, which has been copied and often described in works on carpentry, but it never existed except on paper. M. Betancour has furnished in Bruyère's work the design for the building erected at Moscow, which was commenced under his direction in June, 1827, and completed in the short space of five months: this riding-house is 531 feet in length, and 160 feet in width in the clear. The foundations were dug 13 feet deep, the bricks were made on the spot, and the timber used in its construction was brought from the neighbouring forest. The walls were built up to the level of the ground, 14 feet thick, and above were 8 feet 6 inches.

A scaffolding composed of 1500 posts was raised level with the tops of the walls, for the purpose of supporting the chief timbers of the roofs. The principals were at first 19 feet

apart, one over each pier, and one against each pediment, making altogether 32 pairs: after they were raised, and the supports taken away, it was found that the tie-beams deflected 2 inches more than was calculated upon, and at the end of four months the deflection increased to nearly 5 inches; this occasioned the whole to be reconstructed, and the principals were then placed only 13 feet apart.

The tie-beams were formed of two thicknesses of timber scarfed together, each 12 inches square, one laid upon the top of the other, forming an entire beam 24 inches deep and 12 inches wide; at every 8 feet of its length were introduced iron bolts, 1 inch in diameter; double keys of oak, driven into notches formed at equal distances between the two beams, assisted in resisting the horizontal drawing of the two extremities; the middle of the tie-beams was drawn up 13 inches by the middle or centre post, which is 34 feet in length, or ⅛ of the total span, forming an angle of 21° 48′; above the chief tie-beam are three others placed horizontally at equal distances, which are tied together in a similar manner: a number of designs have been given by the most celebrated engineers of Europe for roofs of this kind, in which iron and timber are used to the best advantage.

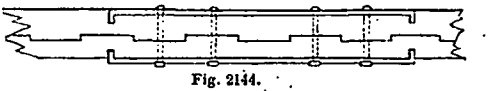


Fig. 2144.

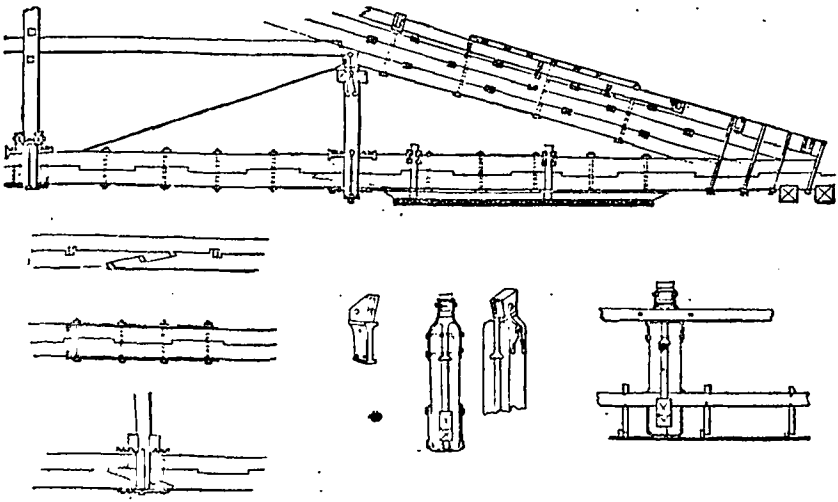


Fig. 2145. ROOF OF THE ORIGINAL RIDING-HOUSE, MOSCOW.

The rafters, if formed of several stout timbers, are capable of supporting considerable weight, when held firmly at their abutments, and the tie-beams strongly bound together, to prevent any drawing out, may be suspended to the principals: a series of iron straps or bands passed round the feet of the principal rafters, and secured to the tie-beams, will

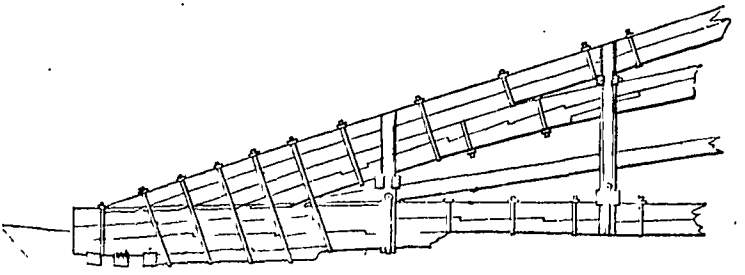


Fig 2146. ROOF OF THE RIDING-HOUSE, MOSCOW.

effectually prevent any rising or spreading of the main timbers; but for still greater security the introduction of an iron rod has been suggested in lieu of a timber tie-beam:

such an arrangement would no doubt retain the curved or bent timbers in their original position.

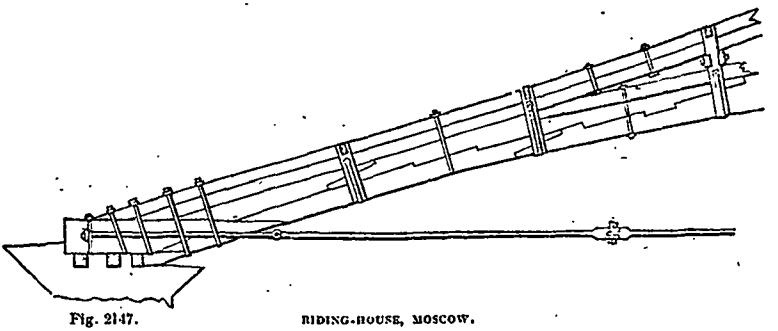


Fig. 2147. RIDING-HOUSE, MOSCOW.

In making the joints where struts and ties unite, great attention is requisite, particularly when they are intended to hold up a suspending rod or timber: the joint should always be at right angles with the timbers, and the head of the piece they are to sustain cut to fit that arrangement, in order to prevent it being pulled through; the irons or stirrups for holding up the tie-beams or other large timbers are attached to a pin made to pass through them, but there is no better method than that which allows the iron to strap entirely around the timber it is to hold up.

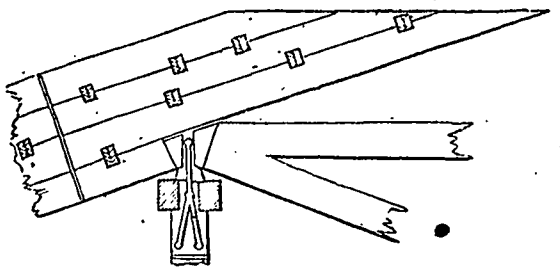


Fig. 2148. RIDING-HOUSE, MOSCOW.

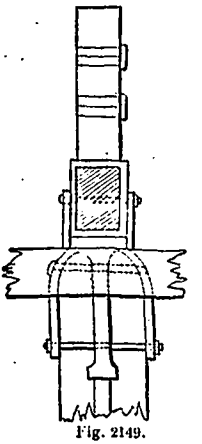


Fig. 2149.

Philibert Delorme, in a work published in 1561, describes a method of constructing roofs and domes with timbers, or rather planks, of short lengths, and which is only objectionable on account of the labour necessary in putting them together: one of these roofs covered the stables of the Tuilleries, at Paris, and after remaining perfectly sound and secure for 234 years was demolished to make way for some improvements in the palace: the arches were formed of two planks, about 9 inches in width, cut into convenient lengths for the required form; this seldom exceeded 4 feet, and when applied to each other to form the rib, they were so laid that the ends of one set came in the middle of the length of the others: mortises in length double their width were then made in them, through which were longitudinal ties, and these had a small wooden pin passed through them, on each side of the circular ribs, to keep them in their upright position, or prevent their twisting. In some of the buildings executed by this celebrated architect, the span of the roof exceeded 60 or 70 feet; two ribs were then used, so put together that they partook of the character of hollow voussoirs, and were very strong; indeed there is scarcely any span where, if properly proportioned, they might not be applied.

Designs are also shown for the construction of girders to carry floors upon this principle, which are well adapted for lofty rooms intended to have coved ceilings, and by placing the ribs in pairs the whole might be covered in a very regular way: when this system is applied to domes, we must commence by tracing out the true curve to be executed, and laying on this mould the first range of planks; when it is intended for a simple roof, the under side of which is not to be formed into an arch, the planks must be placed below the curve line traced; if for a vault, above it, but always in such a manner that the lines may be traced upon them; when the ribs are to be curved above and below, then the

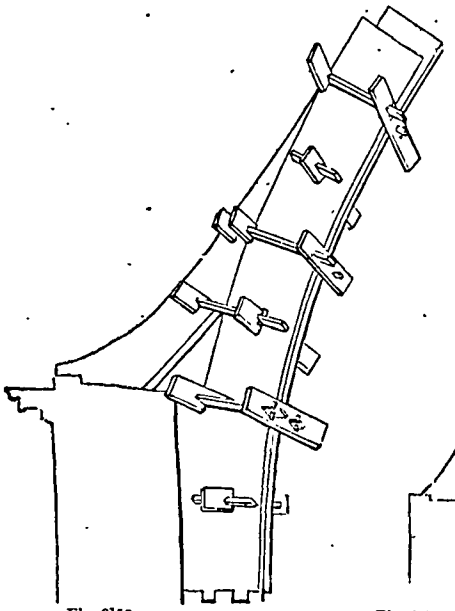


Fig. 2150.

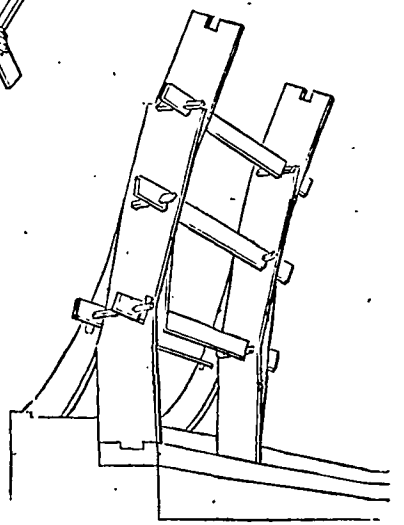


Fig. 2151. PHILIBERT DELORME'S SYSTEM OF ROOF.

planks must cover the two lines of the curve or mould, that the true sweep may be obtained throughout.

Philibert Delorme fixes the length of these planks for every kind of curve at not more than 4 feet, but this rule may be occasionally departed from, when we have to follow a curve which is irregular; it is perhaps better to take such lengths as shall enable us to divide the curve into an equal number of parts, the length of which may vary in each division. When these lengths are determined upon, draw lines perpendicular to the curves, which will indicate the direction to be given to the joints of the boards; after these are cut and adjusted, a second row is so disposed that its joints will fall over the middle of the planks

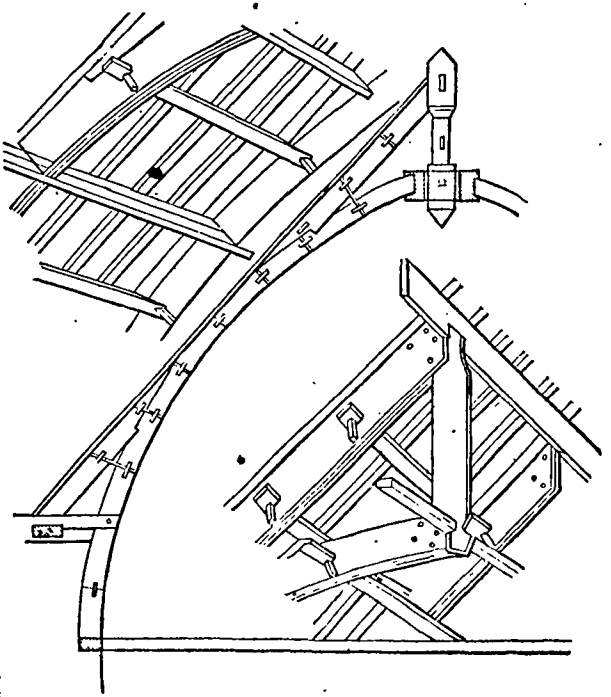


Fig. 2152. PHILIBERT DELORME'S SYSTEM OF ROOF.

of the first row, it being requisite that the planks at the ends should either be half or once and a half the length of the others. When the two planks are properly adjusted, they are then to be united, by first cutting the mortises, through which the ties are to be threaded, which are to unite the principal ribs with each other; these ties are to be of the same thickness as the two planks, and their width four times as much; they are also mortised on each side the ribs, into which are introduced the wooden keys or pegs, the size of which are proportioned to the ties.

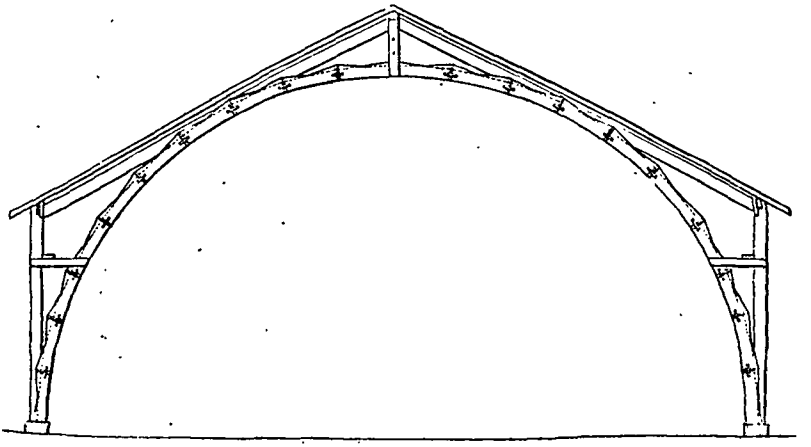


Fig. 2153. SHED ROOF.

As some objection has been made to this construction, on account of the labour required in cutting the number of mortises, making the longitudinal ties, and introducing the pins, that the whole may be firmly united, it may be well to consider if much of this labour might not be dispensed with, and the construction not be weakened: it might no doubt be effected by securing the ties either to the upper or lower parts of the ribs, or both; the boarded covering pinned on to them, or properly spiked down, would almost serve the purpose, and thus avoid an expense of labour, which is rather calculated to weaken the ribs, by so frequently cutting mortises into them. When the ribs can be cut out of 8-inch plank their thickness is to be 1 inch, and this is sufficient for a roof of 25 feet span; for one of 38 feet the width of the planks must be 10 inches, and their thickness 1½ inch; for a span of 60 feet they are to be 13 inches, and their thickness 2 inches; for 90 feet 2½ inches, and for 100 feet 3 inches.

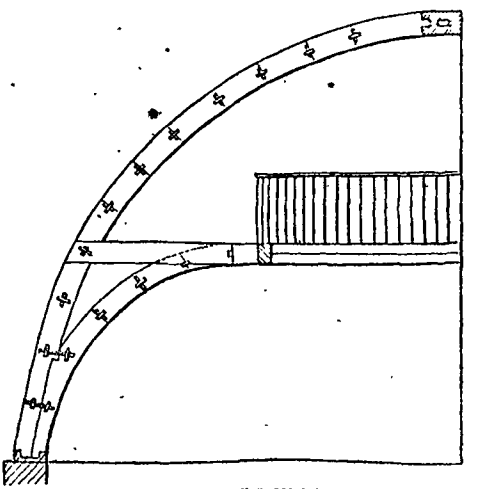


Fig. 2154. ROOF OF HOTEL DE SALM KERSBOURG, PARIS.

At Libourne, in the department of the Gironde in France, is a riding-house with a roof, erected in 1826, under the direction of A. R. Emy, colonel of engineers, which is an improvement upon the principles of Philibert Delorme. The internal diameter at the springing is 68 feet, the clear width between the walls a foot more, and the roof springs 25 feet above the floor. The system adopted for the construction of the ribs was first suggested in 1811 by M. de Saint Phar, who proposed to make the arches of a bridge of bent planks: in the riding-house roof neither mortise nor tenon is used in the arrangement of the bent timbers: and

the construction is so simple that few workmen were required to raise it. There are fourteen main arches or principals, and the walls, though exceedingly thick, are further strengthened with buttresses: each principal is composed of five thicknesses of timber throughout; these were bent to their form on the floor and then raised in a body to their situation.

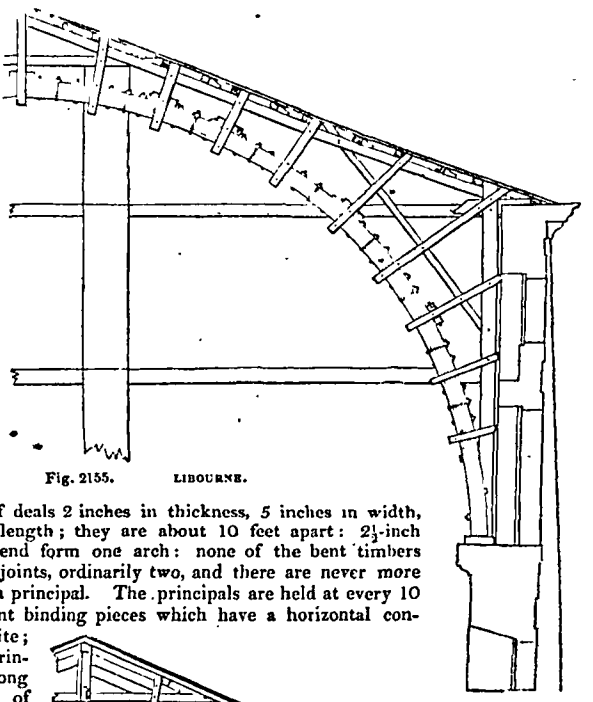


Fig. 2155. LIBOURNE.

Marac, near Bayonne. — This roof, constructed also by M. Emy, in 1826, is 65 feet 6 inches span, and 187 feet in length; each principal is a semicircle, composed of deals 2 inches in thickness, 5 inches in width, and about 40 feet in length; they are about 10 feet apart: 2½-inch planks placed end to end form one arch: none of the bent timbers have more than three joints, ordinarily two, and there are never more than ten or twelve to a principal. The principals are held at every 10 feet distance by pendant binding pieces which have a horizontal connection under the soffite; these passing over the principal rafter form a strong and irresistible piece of framing.

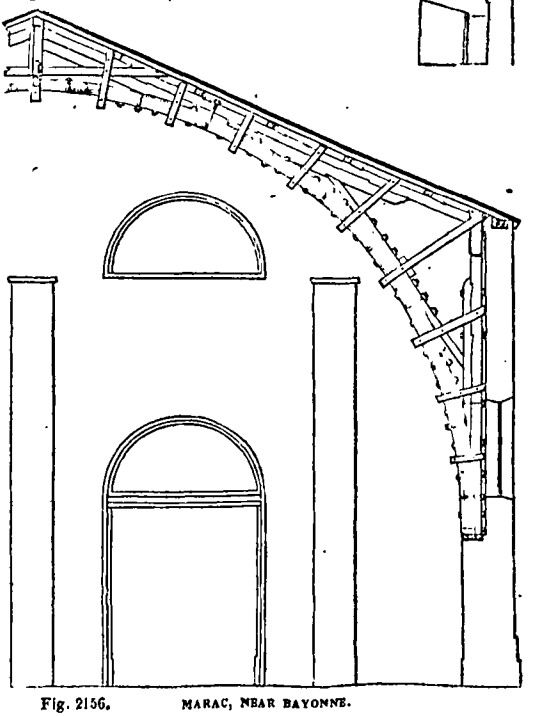


Fig. 2156. MARAC, NEAR BAYONNE.

Where eight or more timbers or thin planks are bent one over the other and bolted through at short distances, the shape of the arch is not likely to be much varied; but with all the precautions that have been hitherto taken this cannot be insured.

The difference between this system of construction and that of Philibert Delorme chiefly consists in the planks being employed in the reverse manner to each other: the method practised by the latter architect would at first appear the strongest, as the depth of the deals or planks is greater than their width, from their being placed edgeways: in the other system, thin boards are bent upon a cylindrical mould; then united firmly together, being rendered strong by their inability to spring; should this, however, occur

in any layer, the whole truss loses its continuity, and becomes weak, and liable to fracture in that part: where iron bolts are passed through, not only do the holes bored to receive them produce mischief by weakening the series of planks, but the bolts prevent that necessary play between each layer which is conducive to its strength: the manner in which the side-pieces are attached contributes very much to the stiffness of the whole, as, being united above and below, there is no fear of the planks starting or changing their position: where tangential timbers can be laid on the extrados of these arches, and united to the pendant side-pieces, a further security against any change of form is insured. The solid content of an arch constructed of bent timber being ascertained, an estimate may be readily made of its cost, and the contrast between it and the ordinarily framed roof easily made: a series of rafters laid longitudinally may carry the slate or tarred paper covering, and all expensive framing be dispensed with.

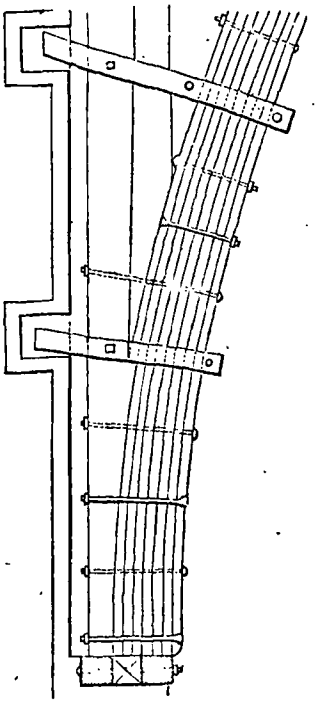


Fig. 2157.

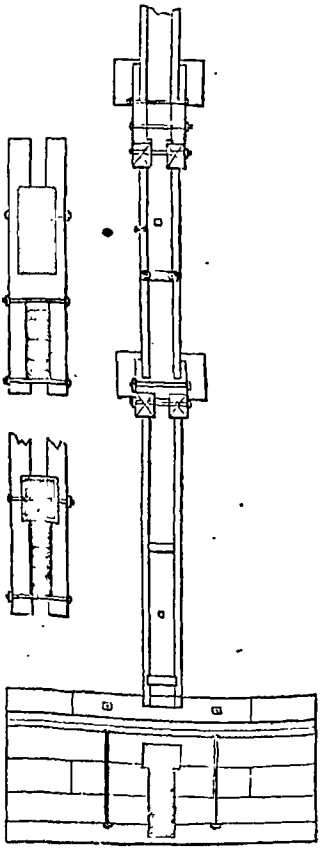


Fig. 2158. SECTION OF PRINCIPALS.

Other roofs of far greater span have been constructed by the same engineer, who after many experiments suggested the employment of a double curved rib having different radii: these, held in at the springing, were in the spandrill space braced by timbers arranged like St. Andrew's crosses; iron bolts or timber binding-pieces pinned at the sides hold the masses together, and form a most effectual support to either tiles or slates that may be laid upon them.

Roofs of bent timbers may be formed in the same manner as adopted for the construction of bridges by M. Wiebeking, who employed pieces of as great a length as he could obtain, and then bent them to the form of the required curve: joints should, if possible, be entirely dispensed with; nothing should be introduced which in any way can weaken the strength of the ribs, or render any part of them liable to decay. As timber shrinks but little in the direction of its length, there is no inconvenience arising from this circumstance, when planks are bent one over the other: whatever change takes place is either in the width or thickness of each layer, and this may occur to a considerable extent without disturbing the strength of the entire rib: but when the timber is not

thoroughly seasoned, by paying attention to the work some time after its execution, the ligatures which strap or hold the several pieces together may be tightened, or wedges introduced, so that each plank may be brought to its bearing.

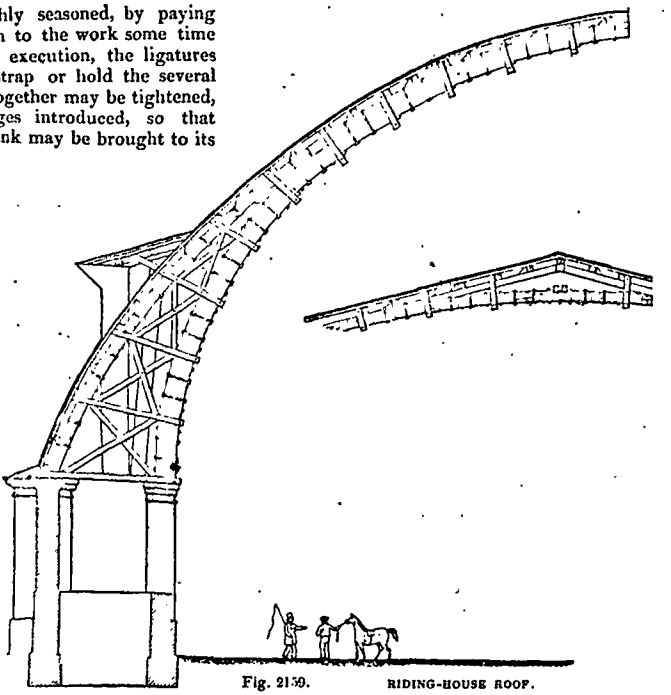


Fig. 2159. RIDING-HOUSE ROOF.

Where brick or stone can be readily obtained, it is often far less expensive to construct a series of arches in one or other of these materials, and to lay the purlins on them to support the common rafters: many custom-houses in France, and buildings destined to receive merchandise, are so formed; semicircular brick or stone arches, 100 feet in diameter or more, span the entire building at every 15 or 20 feet of its length, and these alone support and carry the roof. There is in such an arrangement far less labour required, and as great durability, and the centres used for their construction are of a very simple kind, one serving for each successive arch; running on wheels upon strut timbers or two iron rails they can be readily moved; and as the first course is continued through or over its entire surface, the rib is wedged up, and the weight taken off the rollers beneath it. To form a covering with a flat arch upon this principle, three curved ribs have been employed, which strutted and bolted together have the strength of a solid timber. Bent timbers are made use of for a variety of purposes, and care should always be taken, when heat is applied, to give them the necessary curvature, that it is general and equal throughout.

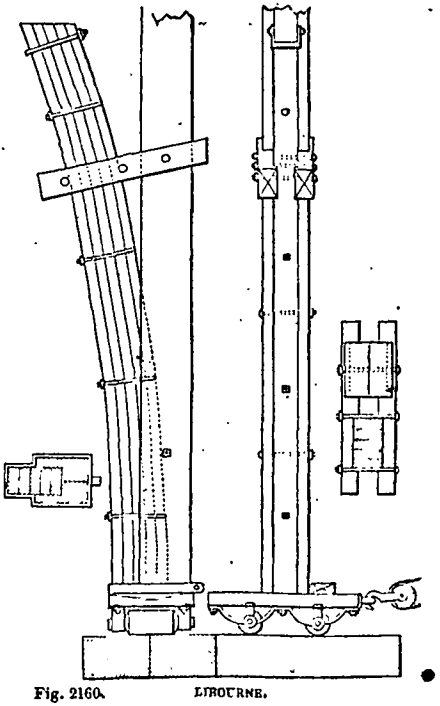


Fig. 2160. LIBOURNE.

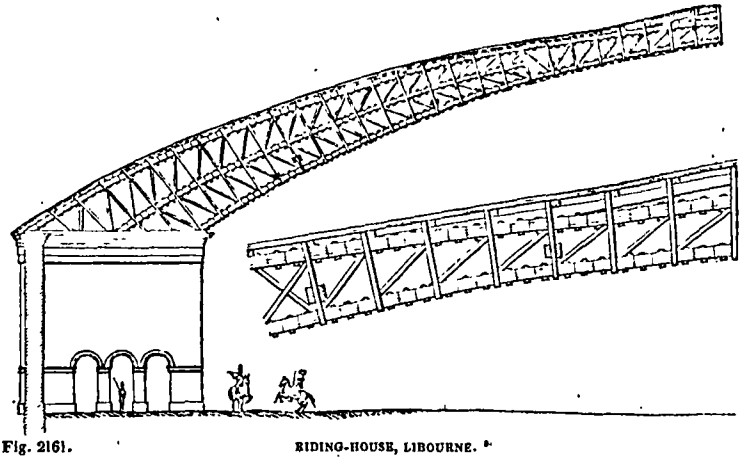


Fig. 2161. RIDING-HOUSE, LIBOURNE.

Sheds for Ship Building are of various kinds: those constructed at Rosieres in France are very simple, resting upon posts placed upon a solid mass of masonry: a series of such spans must be rendered secure at their commencement, and the two outer need some additional security at the feet of the rafters to prevent their spreading. At the ship-yards of L'Orient, the roof, composed of iron and bent timbers, is supported by arches and columns of masonry; light being admitted to the ship-wrights by dormers constructed along the sides at the springing of the roof: occasional ties are here requisite, which are above the vessel when it is let off the blocks to be launched.

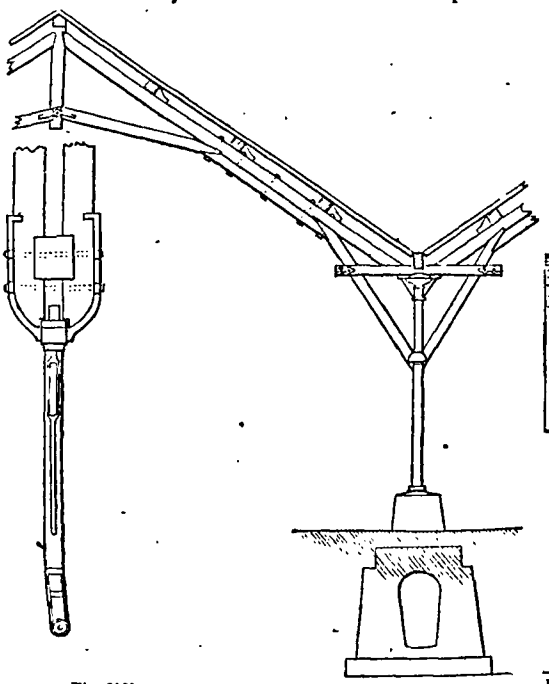


Fig. 2162. SHEDS FOR SHIP-BUILDING.

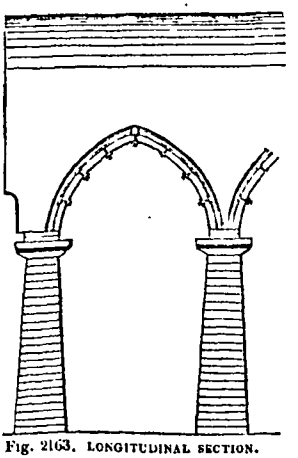


Fig. 2163. LONGITUDINAL SECTION.

The walls of masonry and post above are well adapted for the struts and braces introduced to receive the middle gutters placed between the several roofs in succession; and the water is ingeniously led from them by pipes into a drain formed within the wall below, and conducted into the ocean without injuring the inclosure: when the timber is well seasoned, properly framed together, and all injurious effects from the rain prevented, roofs formed in that manner will endure for a length of time: it is always necessary to provide against the action of strong winds by bracing the sides in every possible position.

Where timber cannot be obtained of sufficient scantling for the principal rafters, they may be made in two thicknesses, or be placed side by side, and the hanging-post, which is suspended from the apex of the roof, may be secured by an iron head cast to receive the principals, and to admit of the introduction of a screw-bolt or iron tie, against which the lower struts may abut.

Roofs of large span where Tie-beams are omitted.— As ships are now built under cover, and the dock is protected from the weather, the most convenient as well as economical construction is that of the roof of equilibrium: many of these roofs are upwards of 100 feet span, formed of a combination of trusses, so supported that they perfectly balance, in the same way as the principals of a Mansard roof.

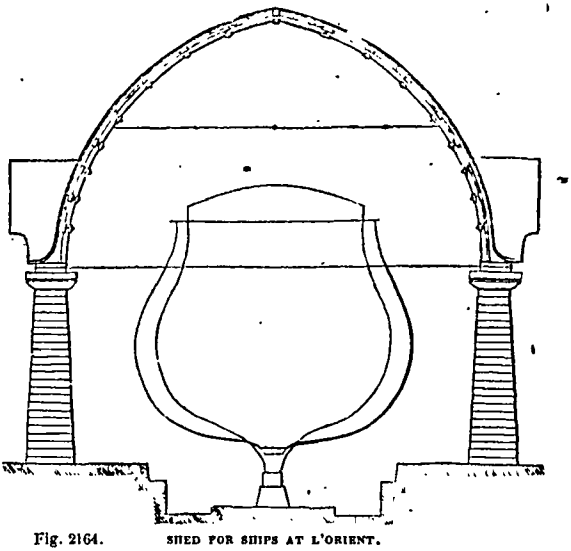


Fig. 2164. SHED FOR SHIPS AT L'ORIENT.

To balance a roof or a pair of principals, framed alike on both sides and loaded equally, so that it does not fracture, requires some little knowledge of the various strains to which its parts are subject, and also care in the direction given to the posts that support it: for as these posts constitute the main strength, every cross strain by which they can be affected tends to weaken them as supports.

The centre of gravity of one-half the framing, which is easily found, we will suppose at C, fig. 2165. and 2166.; a vertical line carried through this point from *g* will cut the horizontal line, *c b*, drawn through the middle of C, at *b*: a line drawn from this point *b*, through B, will give the proper direction for the post; this, however, is sometimes, for the sake of convenience, placed perpendicularly; the weight of the roofs has then been found to cause fracture at B C, or to yield at the points A, B, C, *c*.

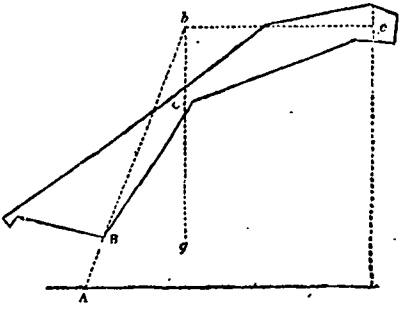


Fig. 2165.

Timber roofs are supplanted by others constructed entirely of iron, partly cast and partly wrought: some of wrought-iron, lately erected at the Woolwich Dockyard, are

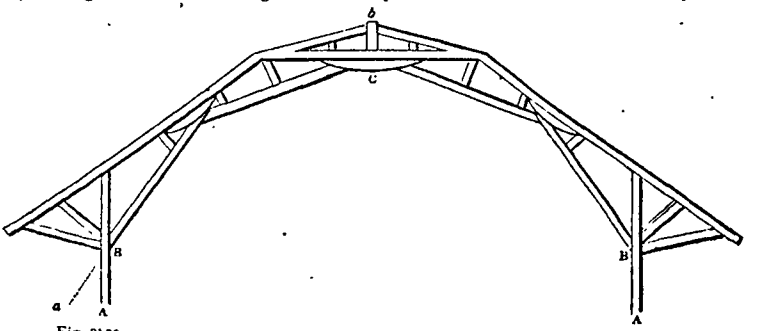


Fig. 2166

SHEDS FOR SHIP-BUILDING.

novelties of their kind, and admirably fitted for their purpose: although their first construction may be far more costly, they will in all probability supersede timber structures, on account of their greater security against fire.

It has been suggested to form roofs of bent timber for the purpose of covering the building docks in our shipyards: when the depth of a piece of timber does not exceed $\frac{1}{10}$ of its length, it may be curved easily, and its elastic force not be destroyed, if its versed sine is not more than an eighth of its span: two pieces may be so bent and laid one over the other, by first securing one end by a cord or iron strap, and then pulling down the second piece to the back of the other; a number of layers may be thus brought down upon each other, and secured by bolts or ties.

Domes and Cupolas.—To construct these in timber it is usual either to frame trusses entirely across the opening, or, where the ties cannot be allowed, to form the ribs, which carry the covering like a series of centres, thus dispensing with the ties. The dome of the *Val de Grace* at Paris is an example of the first kind; it is composed of four principal trusses, two of which cross the others at right angles, leaving an opening to the cupola in the centre: sixteen half trusses converging to the centre, arranged at equal distances around the dome, carry the rafters, which support the covering: such constructions

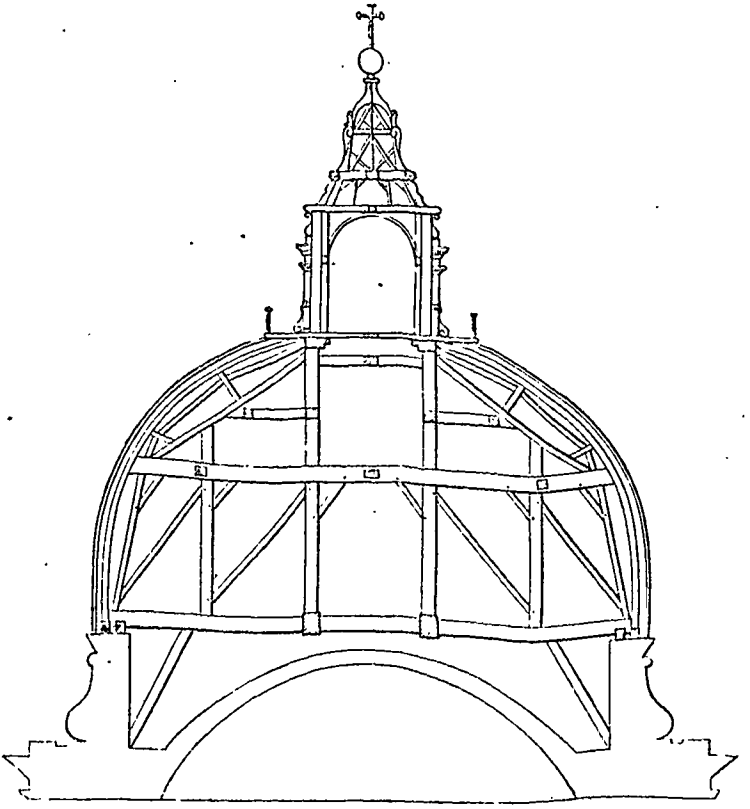


Fig. 2167. DOME AT VAL DE GRACE AT PARIS.

as the above admit of application where the exterior effect is alone considered, or where it is merely required to cover in and protect a hemispherical dome of masonry: it is evident that the interior cannot be made available either for use or decoration, in consequence of the timbers which are introduced.

Dome of the Invalids, at Paris, whose external diameter is 90 feet, is another example, composed of two principal trusses, which cross in the middle at right angles, and unite in a double upright post; each quarter of the dome, or the space between these principal

trusses, is filled in with two half trusses of the same kind, and four smaller ones, which are sustained by great braces in their proper position.

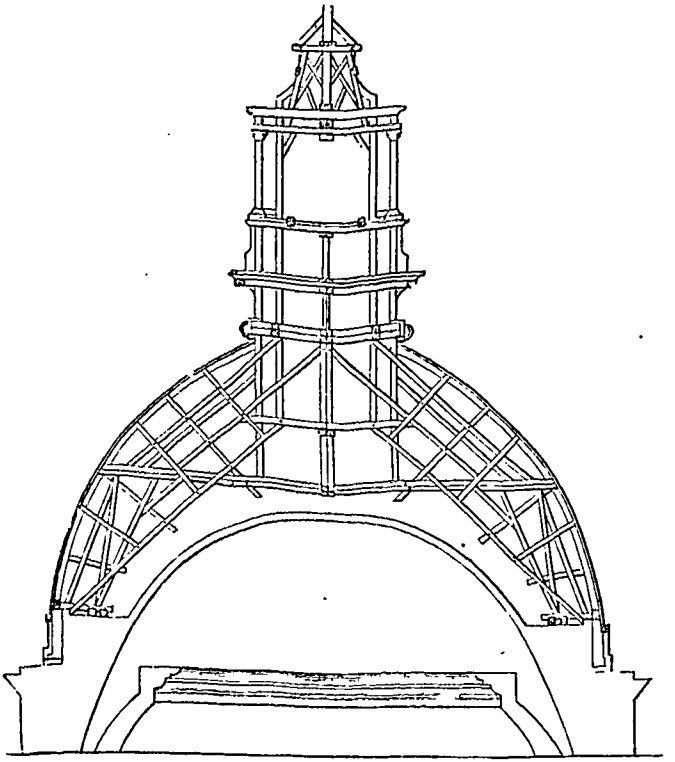


Fig. 2168. DOME OF THE INVALIDES AT PARIS.

Dome of the Assumption, at Paris, designed by Errard, is an example where the interior may be rendered available to effect, and to the purposes of decoration; its principles are laid down by M. Stierme, in Krafft's work on carpentry: two trusses cross each other at right angles in the middle, and these, with twelve others arranged intermediately around the dome, all converge to the centre, and carry the lantern. The principle adopted in the setting out was to form first a square, the side of which was determined by the height to the under side of the lantern: where the diagonals of the square so set out cross each other a point was established, determining the radius of the inner dome, which is perfectly hemispherical: this point is found by elongating the line of face of the inner wall, until it intersects the diagonal, establishing the height at which the horizontal tie is to be placed. The inclined posts, which carry the chief weight, are tangents to the curve of the inner dome, and are each framed into two struts, that support the outer rib of the dome, which carries the covering: five horizontal and concentric ties, at regular and parallel distances, maintain these four principal ribs in their true position, and, being framed into them, bind them together.

The Church of St. Mark, at Venice, exhibits a dome of very early construction, its date being assigned to the year 1085; after its erection some additional timbers were introduced by Giacomo Sansovino, in 1530, which act as inclined shores to bear up the cupola: the outer diameter is about 51 feet, and its height 60: it forms a covering to a brick vault beneath it. The lower portion is cylindrical, and is framed throughout its circumference with upright posts, set at a distance of about 2 feet from centre to centre; they are united at the top and bottom by circular plates. The hemispherical portion of the dome is composed of stout double planks, so put together that each forms a sort of rib; these are united by four horizontal ties placed at regular distances: the exterior is covered with planking bent round to receive the lead.

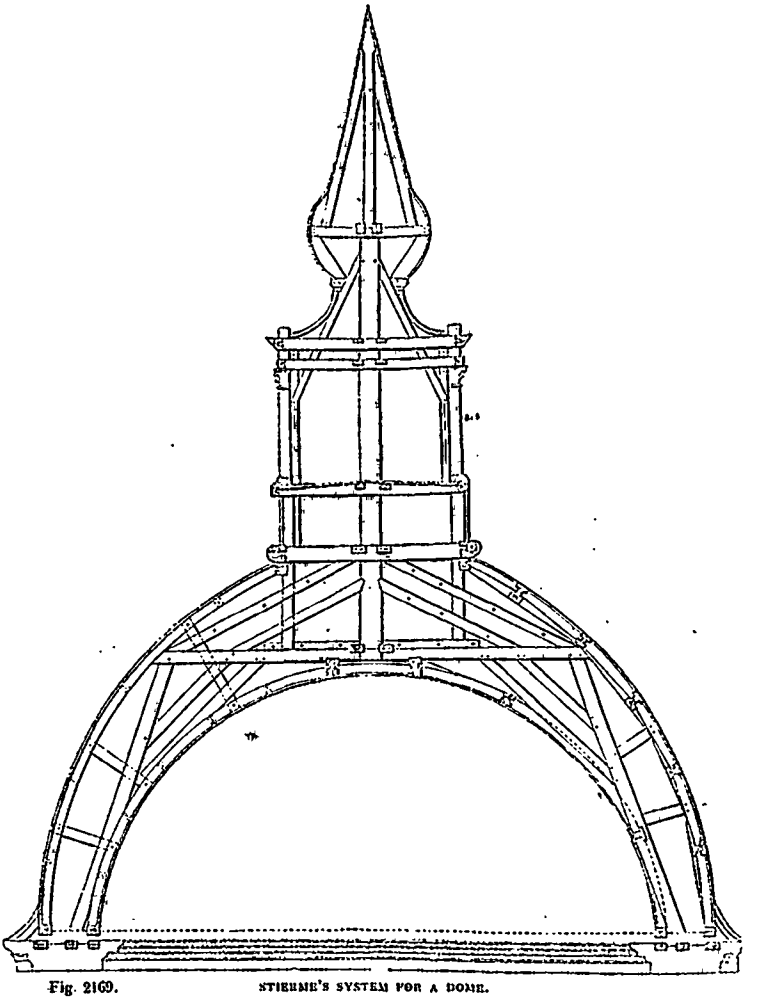


Fig. 2169. STIERNE'S SYSTEM FOR A DOME.

In the example given of Stierne's construction of a dome, we have a horizontal tie introduced above the curve, into which are framed two upright posts that form the sides of the lantern above: on the drum wall or cylinder that carries the timber dome two circular plates or curbs are first laid, generally formed of two thicknesses well bolted together: considering the dome to consist of four such trusses, as shown in the figure, they may be placed to cross at right angles, each pair being parallel to the other, and situated at a distance apart that suits the framing of the lantern.

The Church of the Salutation, at Venice, has a timber dome, the outer diameter of which is 80 feet; it covers an interior brick hemispherical vault, which has an opening of nearly 43 feet diameter. The exterior is formed of planks, in four thicknesses, laid one over the other, united together by nails: ninety-six of these ribs, each about 6 inches in thickness, have their lower ends let into a circular plate, formed of four thicknesses of plank, which lie over the attic cornice: at the top they are framed into a curb or plate which bears upon eight columns, placed round the opening of the brick dome: the lantern and its balustrade externally is partly supported by this arrangement; eight additional posts are introduced to carry the weight of the obelisks, which surround the base of the lantern. To keep the ribs which form the outer dome from spreading, they are hooped round with iron at about one-third of their height, the hoop being 5 inches wide,

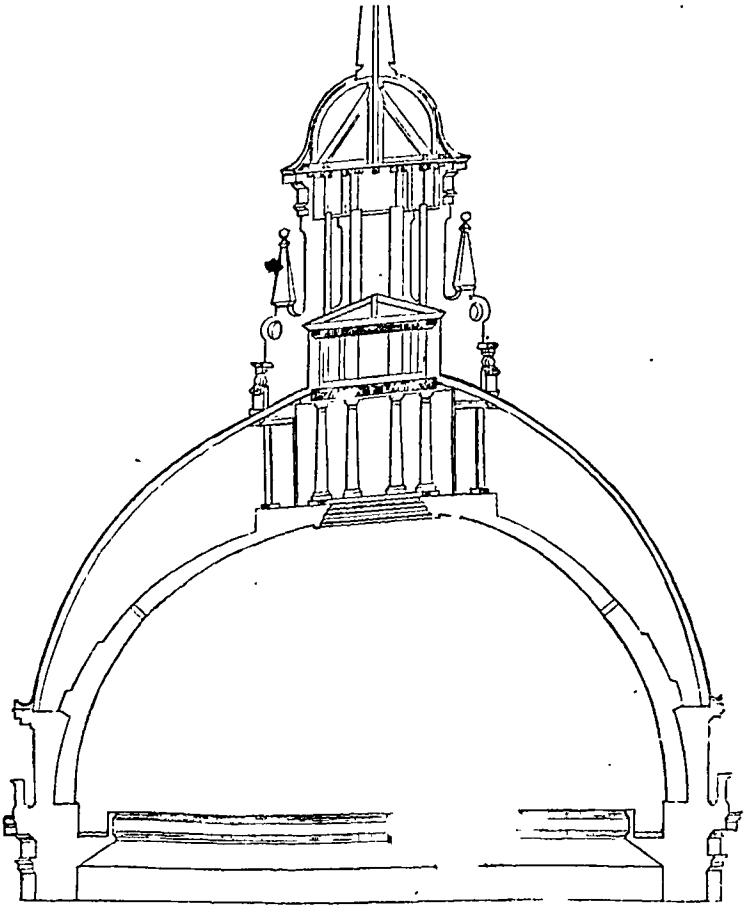


Fig. 2170. DOME OF THE CHURCH OF THE SALUTATION AT VENICE.

and half an inch thick, secured by an iron pin to each rib: stout laths are nailed on the backs of the ninety-six ribs to carry the lead covering; and where the joints are formed, additional wooden rolls are fixed to dress the lead round.

CHAP. XXIII.

TIMBER BRIDGES. — SWING BRIDGES. — DRAWBRIDGES. — ROPE BRIDGES. — CENTERING. — SCAFFOLDING.

Timber bridges are general in all countries where timber abounds, and where cheapness and expedition are important; it has its objections in being less durable than either brick or stone, but, if covered and protected from the weather, may be made to last a considerable time. Bridges constructed of timber, so that they may be easily repaired when decay takes place, have also their inconveniences, as the traffic across them must be stopped whilst the workmen are employed: they are undoubtedly of very early invention, and may be considered as strong platforms crossing rivers, and preserving an uninterrupted communication. Among those built by the Romans, we have the description left

us by Julius Cæsar of one over the Rhine: Alberti, Palladio, and Scammozzi, have each attempted to design its form; but their ideas upon the subject differ materially.

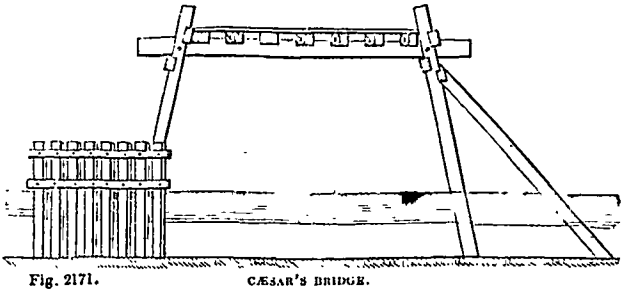


Fig. 2171. CÆSAR'S BRIDGE.

Cæsar tells us that two pieces of timber 18 inches square, after being pointed at their lower ends, were sunk into the river, and afterwards driven 2 feet distance from each other by means of machines; these piles were inclined a little; two others were driven at a distance of 40 feet opposite them, inclining in the contrary direction; these two pairs of piles

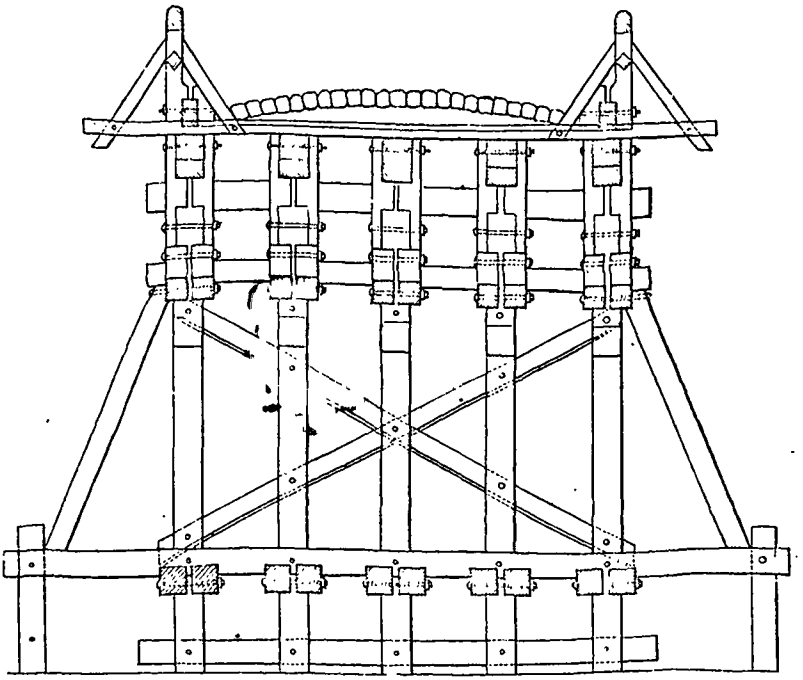


Fig. 2172. CÆSAR'S BRIDGE.

were united by a transverse beam at the top, which was in thickness 2 feet, and properly secured: on these were laid joists in the direction of the breadth of the river, which were covered with hurdles to sustain the road. On the side below the stream inclined piles were driven, which supported the bridge against the force of the current, and above the bridge were others, to protect it from injury against floating masses, as trees or boats: it was completed, and the troops were enabled to pass over it in ten days.

Alberti fastens the girders to the heads of the piles by ropes instead of two bolts (*binis fibulis*), as perhaps the text implies: Palladio has introduced two pieces of timber for their supports, halved and bolted into the sides of the inclined piles: Scammozzi gives a double tie of cordage: Perrot d'Ablincourt attaches these cross-beams or girders by means of several enterties, which seems justified by the text.

Trajan's Bridge over the Danube is shown in bas-relief upon the triumphal column erected to that emperor in Rome: its construction was timber resting on stone piers, and so framed that it was both solid and durable; three rows of concentric arches united by binding pieces formed each division; these abutted upon timbers radiating with the curve, which were framed into heads and sills, again strengthened by braces and struts; the joists which carried the floor traversed the bridge, and rested on strong plates which were laid on the backs of the timber arches. The parapets were formed of perpendicular pieces with a St. Andrew's cross between them, united at the top and bottom by a longitudinal sill and head.

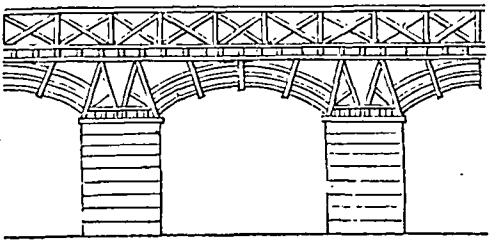


Fig. 2173 TRAJAN'S BRIDGE.

This construction is admirable, though more strength might have been introduced in the carpentry, which rests on the piers and forms the abutments to the concentric arches which span the river; they would then have resisted more perfectly the thrust to which they are subjected; horizontal timbers driven between the struts, particularly between the heads of the shorter, would have added materially to the strength, and given those timber abutments greater power of resistance to compression.

The Pontus Sublicius at Rome was an earlier wooden bridge, and constructed 500 years before the Christian æra, under the reign of Ancus Marcius, one of the first kings: all that we know of it is that it could be taken to pieces, and that neither iron nor nails were used in its construction; the timber was united by solidly framing it together, using wooden pins to secure it.

Sublicius is derived from *sublica*, a pile, which indicates that the platform or roadway was supported by them, driven at regular distances from each other: this bridge is mentioned as that so valiantly defended by Horatius Cocles. Most of the timber bridges that have been constructed since the fall of the Roman empire exhibit in their design one or other of the twelve principles which we are about to describe.

The first principle that we can adopt is that of a single beam, or one composed of many thicknesses: if the lower, which spans from A to B, is laid flat, the others, as P′, C′, P, C,

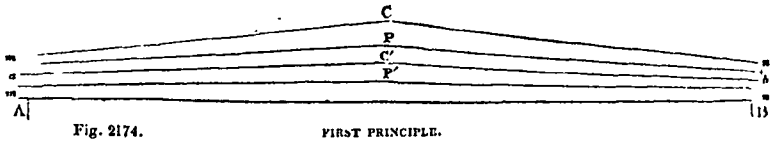


Fig. 2174. FIRST PRINCIPLE.

may be cut tapering, and as they are laid upon each other either bolted or strapped together to make one entire mass: by this means the requisite increase of depth towards the centre may be given, to support any weight for which it is destined.

The second principle, as adopted at the bridges of Schaffhausen, Zurick, Landsberg, Wittingen, &c., has the tie-beam to constitute the abutments for the compressed timbers; consequently there is no thrust exerted against the walls, as the entire timber-work may be regarded as a trussed frame.

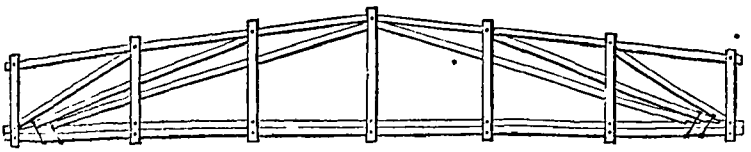


Fig. 2175. SECOND PRINCIPLE.

The third principle was introduced at the Kandel Bridge by Joseph Ritters, but here it is requisite that the abutments should be made sufficiently strong to resist the entire thrust: sometimes the tie cannot be made use of; then we are obliged to adopt some such method as here shown.

The fourth principle exhibits a different arrangement for beams that are compressed;

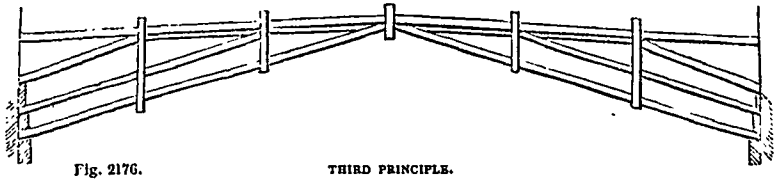


Fig. 2176. THIRD PRINCIPLE.

instead of abutting against the pendant timbers, as in the third example, they are laid over each other, and constitute in effect but one beam.

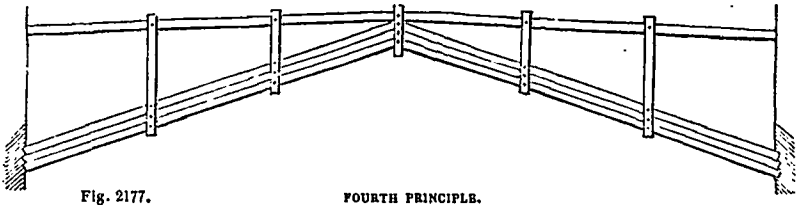


Fig. 2177. FOURTH PRINCIPLE.

The fifth principle is a modification of the preceding, and is particularly adapted to a bridge where long pieces of timber cannot be obtained: the bridge of St. Clair, over the Rhone,

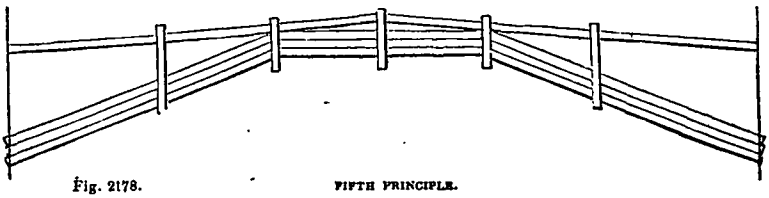


Fig. 2178. FIFTH PRINCIPLE.

at Lyons, is so constructed, as it was not found possible to obtain timber of sufficient depth and breadth.

The sixth principle was adopted at the bridge of the Mulatière at Lyons, over the Saone; such were the bridges constructed over the Thames formerly at Kingston and Walton:

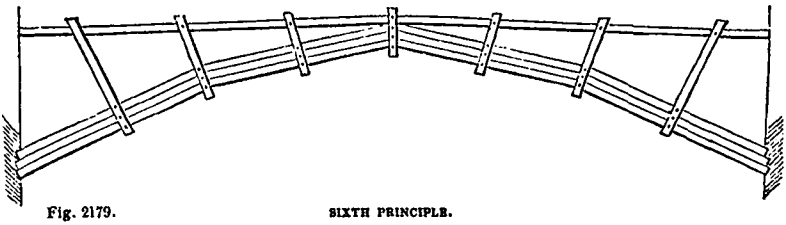


Fig. 2179. SIXTH PRINCIPLE.

there is no advantage gained by shortening the beams, because the angles of junction being more obtuse, the strain in the direction of the length is considerably increased.

The seventh principle exhibits a framed rib, but it must be remarked that the weight to

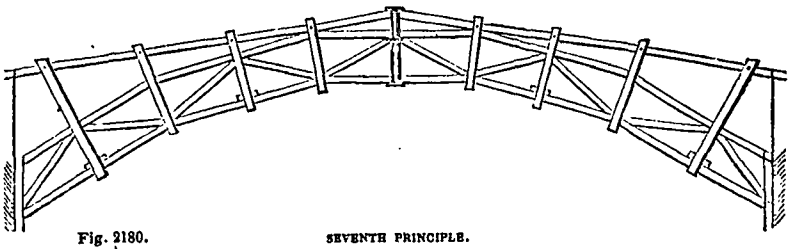


Fig. 2180. SEVENTH PRINCIPLE.

be applied in the middle must proportion its depth: a number of curved ribs may be so put together that they will resist either extension or compression.

The eighth principle shows a different combination of bent timbers, where the framed voussoirs are dispensed with, which sometimes are found objectionable, from the difficulty of making all the joints fit properly, and their liability to decay.

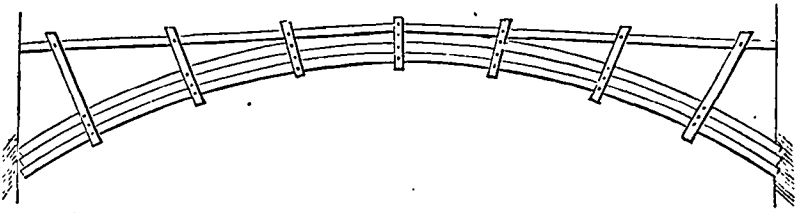


Fig. 2181. THE EIGHTH PRINCIPLE.

The ninth principle does not materially differ from the last; the pendant binding pieces are placed perpendicular, and do not diverge to the centre, from whence the bent timbers are curved.

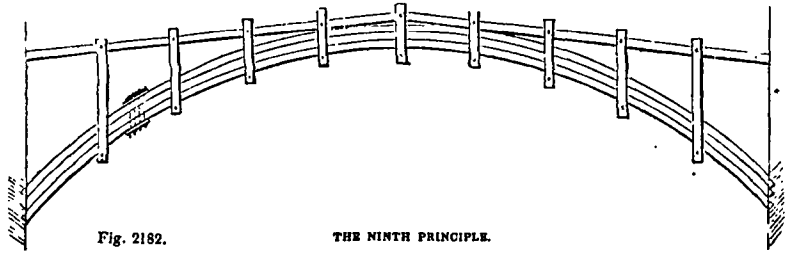
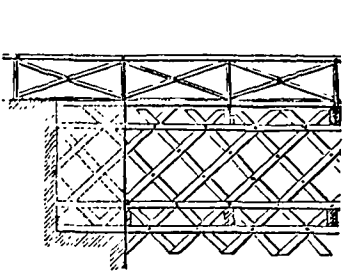


Fig. 2182. THE NINTH PRINCIPLE.

The tenth principle is a continual lattice, or open beam, so proportioned that it has been made to span very wide rivers in America.



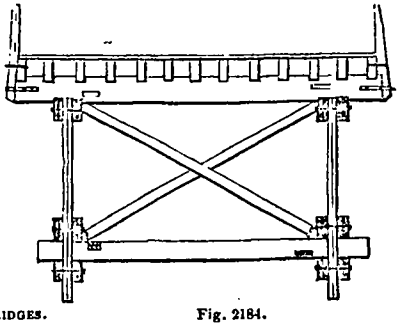


Fig. 2183. LATTICE BRIDGES. Fig. 2184.

The eleventh principle, called Long's, does not consume so much timber or labour, and has been much employed in America: it consists of a series of St. Andrew's crosses between

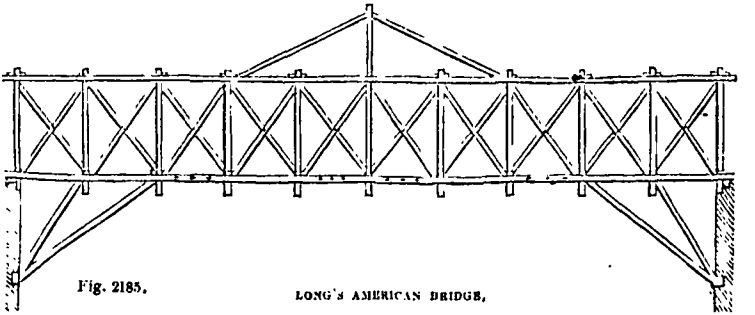


Fig. 2185. LONG'S AMERICAN BRIDGE.

upright posts, the head and sill into which they are framed being bolted well together by iron rods: the depth or height of the framing is proportioned to the span; the string pieces are formed of three timbers, the posts and braces of two, and the counter beams of one.

The twelfth principle is that of suspension, and is admirably adapted to spans of almost any required extent: the platform is supported by hanging up the under transverse timbers by iron rods, which pass over a saddle, also of iron, placed at the top of two long piles, driven in with the requisite inclination to support them. The chains, which are suspended from pier to pier, are sometimes placed beneath the platform, as in fig. 2189., upon the principle now generally used for trussing longitudinal timbers, which system is far more economical.

A combination of these principles is sometimes found adapted to bridges of different span: Bruyere has given us the method by which we may form foot and other timber bridges in a firm and solid manner.

Kraft, in his work on carpentry, has suggested for foot-bridges the hexagonal struts and binding-pieces, as shown in fig. 2190, 2191.: and the same author prefers for bridges, over which loaded carriages are to pass, that the timbers should be arranged polygonally, and held together at their joints by binding-pieces: over the piles a St. Andrew's

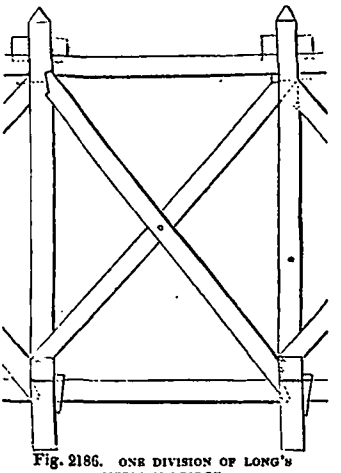


Fig. 2186. ONE DIVISION OF LONG'S AMERICAN BRIDGE.

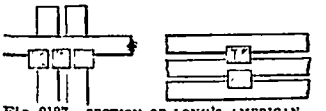


Fig. 2187. SECTION OF LONG'S AMERICAN BRIDGE.

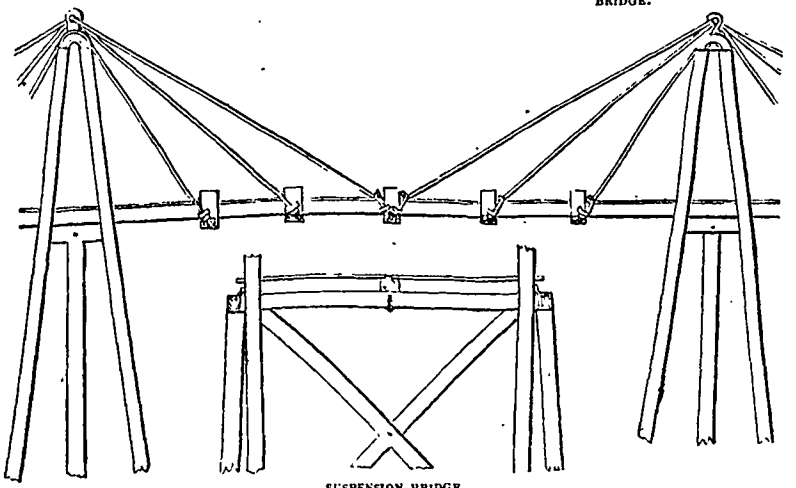


Fig. 2188. SUSPENSION BRIDGE.

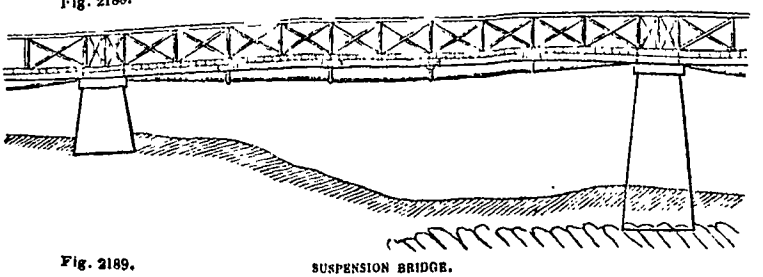


Fig. 2189. SUSPENSION BRIDGE.

cross is constructed, upon which the timbers that carry the road are laid. Another form for bridges of considerable span is that in which a

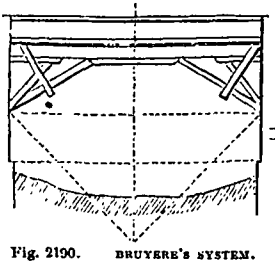


Fig. 2190. BRUYERE'S SYSTEM.

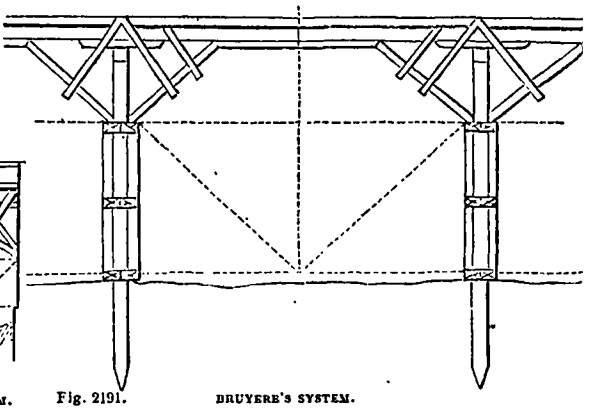


Fig. 2191. BRUYERE'S SYSTEM.

series of polygonal timbers cross over the junctions of the ends of each other, and are then bound together by the pendant or inclined binding-pieces.

In the system adopted by Bruyere the pendant binding-pieces are placed parallel with the sides of a square, the diagonal of the square, in bridges of small span, being a perpendicular let fall from the centre of the bay, (fig. 2190.) When the distance between the piers is increased, the timbers that support the platform have an hexagonal form, as in fig. 2191., the struts which spring from the heads of the piers being placed parallel with the sides of the square: the several thrusts and pressures are all admirably provided for in these designs.

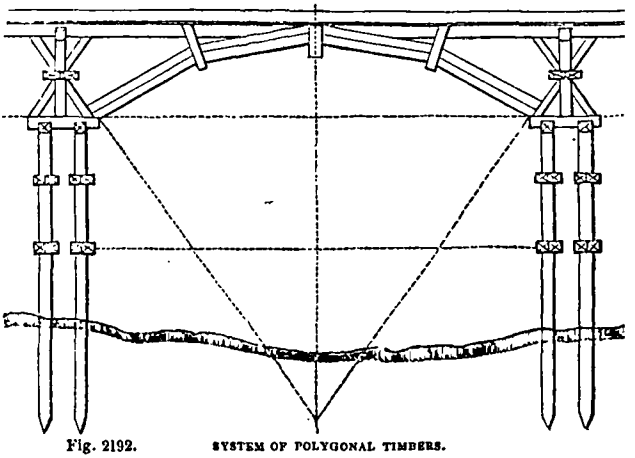


Fig. 2192. SYSTEM OF POLYGONAL TIMBERS.

When the stream is tranquil, and not subject to floods, piers may be introduced, so as not to interfere with the navigation; and their number may be lessened, where long pieces of fir timber can be obtained; where oak is used the pieces should be as short and of as small a scantling as possible, to avoid expense: but whenever piers of masonry can be adopted, they should be preferred, as the ice in its descent cannot injure them, if properly constructed and protected.

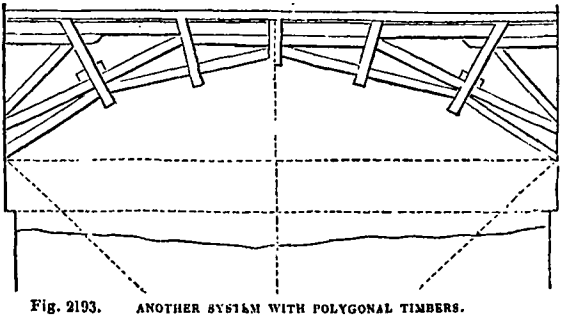


Fig. 2193. ANOTHER SYSTEM WITH POLYGONAL TIMBERS.

The system of polygonal timbers offers considerable facility for the employment of short lengths, and is adopted for small bridges, where economy is an object; but a number of joints increases the liability of movement in the parts, and it is necessary to in-

troduce struts and binding-pieces in the position, where such a change in the arrangement is likely to occur.

The timber employed in the construction of a bridge requires to be considered in a different manner to that in ordinary buildings: besides the weight of the framing and roadway, there is a constant vibration, from the movement of carriages and passengers over it, and the timbers so acted on affect one portion at a time. As the load passes over, the timber immediately bearing it bends, and recovers itself when the weight is removed: experience, however, proves that we must not permit any portion of the structure to bend beyond its powers of elasticity or its ability to recover the original form; constant action upon timber in the course of time destroys its flexibility, and experiment teaches us that the elasticity of timber decreases with time, and particularly when subjected to the effects of a momentary action by a load passing over it. But the momentary load is less dangerous to its strength than that which acts continually, so that in valuing the strength of a piece of timber to support the heaviest weight to which it may be subjected when immovable, there will be no danger in applying it to a bridge. Timber of good quality and properly seasoned endures a great length of time, particularly if protected from moisture and the worm: the alternations of humidity and dryness occasion a constant change in the movement of the fibres, and in the course of a few years an entire disorganisation.

When trees are growing, that portion of the wood nearest the heart is the strongest, but when their growth ceases, the other portions acquire the same strength, and when on the decline, the change commences at the heart, so that the outer parts, or those nearest the bark, are the most to be depended upon: when decay has commenced at the pith or heart, it extends by degrees until the whole timber perishes; too much care cannot be taken in the selection of timber, and it is well to observe the dimensions of the trees in the forests, that afford the supply, and to choose only those which are beneath the average diameter, so as to be certain that decay has not already commenced. Timber is often cut down the middle for the purpose of ascertaining if the heart be sound; when the concentric rings are destroyed there is less resistance offered to pressure than before.

Where timber is free from attacks by the worm, and no change has taken place at the heart, humidity and alternate dryness are the only effects we have to guard against: the fibres on the exterior become more saturated with moisture, which they take in from the atmosphere, and again readily yield when the air is heated, and the surface being that portion more exposed to frequent alterations, its disorganisation will commence first, the fibres lose their elasticity, and, no longer exerting any resistance, a diminished scantling is the result.

Timbers employed in bridges may be considered as losing a portion of their scantling every year, and consequently their strength: the bridge in the course of time, no longer able to support its load, must fall, and this ruin is delayed so long as the proportion given to the timbers admits of the annual loss, without reducing its scantling below the minimum that would bear the weight imposed upon it: in consequence of the cost increasing with the extra scantling of the timbers, we are restrained from making them perhaps so large as they ought to be in the first instance; true economy, however, consists in using the quantity of timber sufficient to bear the required weight.

There can be no difficulty in ascertaining the weight or load to which any piece of timber is subjected, after the rules already given: these may be applied to timber either singly or collectively, but they must be carefully analysed and calculated.

Of Piers.— These are usually composed of one, and sometimes of several rows of piles, driven in the direction of the current; but the best plan is to drive the first so that their heads may be cut off immediately below the water, and on them to construct a platform of timber, into which the posts which carry it may be framed: this construction has a considerable advantage, as the parts above water, which more frequently go to decay, can be easily repaired, whilst that constantly immerged endures for a greater length of time.

There are various methods of uniting these timbers together; one is by iron pins, about 3 feet in length, passed through the horizontal timbers into both the upper and lower piles;

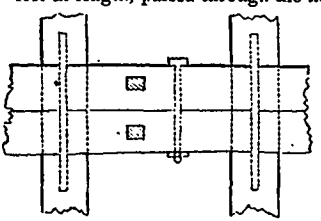


Fig. 2194. PLAN OF CROSS TIMBERS.

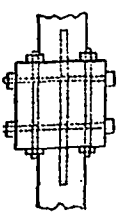


Fig. 2195.

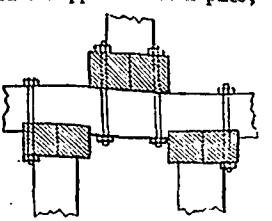


Fig. 2196. PIERS.

the horizontal timbers are also strapped to them by alternate horizontal and vertical iron bars, the upper timbers of the pier being level with the surface of the water.

The head of each pile should be well bolted and secured to the timbers with which it is capped, or which holds it to the others in the same row: the bridging-piece, or bearer, is laid transversely upon the capping, as fig. 2196., and should be strapped securely down, and where other perpendicular posts rest upon them they should bear upon a plate, continued through the entire length of the pier: mortises and tenons should be avoided as much as possible in the framing of all wooden bridges, and where any junction of the timbers is to be made, it should be formed by iron bolts or straps.

When the river has a considerable depth, a double row of piles is requisite, for it would be hazardous to depend upon a single one: the lower range is driven about 8 feet apart, or from centre to centre, and a capping piece, extending the whole breadth of the bridge, is laid upon the heads of each row; an intertie crosses these, and on it is placed a third timber, extending the breadth of the bridge, into which is framed the post, which carries the platform; these timbers are all well framed and bolted together. Timber 12 inches square has sufficient strength to bear any weight to which an ordinary wooden bridge is subject, though double rows of piles are often used: where many rows are requisite, they must be protected by sterlings so contrived as to prevent ice or other floating bodies from injuring them, and the best method of effecting this is to drive two rows of piles tending to a point, in front of the pier to be protected, and plank them so as to resemble a wedge; upon the top of this, which is level with the surface of the stream, is laid an inclined piece of timber against the pile, which may be strutted on to the heads of the piles forming the wedge, and, by putting an iron edge to resist the ice, be made very efficient. The posts composing the upper part of the piers are always terminated with a capping, and if their height be considerable they should be supported towards the middle by one or several courses of horizontal binding-pieces, the effect of which is to support the posts in a parallel position: to prevent their going out, there must be inclined or discharging pieces; one of the best examples of their application is at the bridge of Fresingen. Experience has proved that piers of this kind, which resist perfectly the shock of the ice, and are preserved from injury by the fascines which surround the foot, are sufficiently solid to carry the largest arches of carpentry: but notwithstanding all the precautions possible, the timbers of which they are formed must be destroyed before those of the arches which they carry, and it is preferable to establish these arches on piers of masonry, whenever the foundations do not render it totally impracticable: if, however, this difficulty does occur, and timber can be procured sufficiently long to form the large piles necessary for the construction of the piers, the arrangement adopted by M. Wiebeking may be employed with advantage. In many cases also the piers may be constructed with cylinders of cast-iron, traversed by a piece of timber, which would give them the greatest solidity.

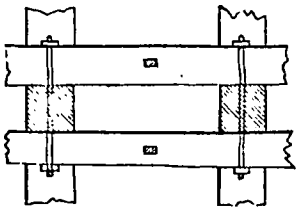


Fig. 2197. PLAN OF TIMBERS.

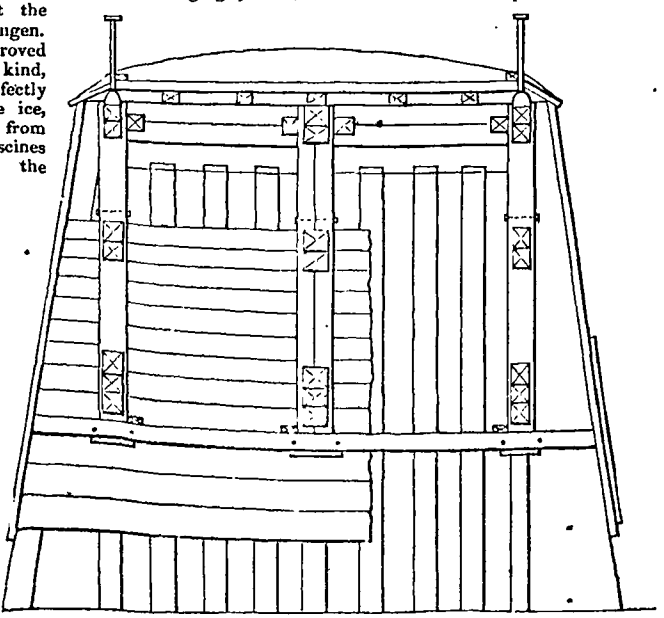


Fig. 2198. FRESINGEN BRIDGE: TRANSVERSE SECTION.

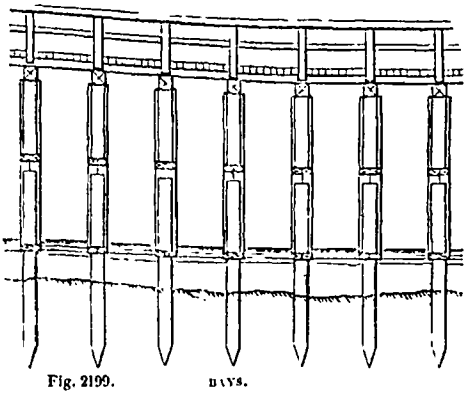


Fig. 2199. BAYS.

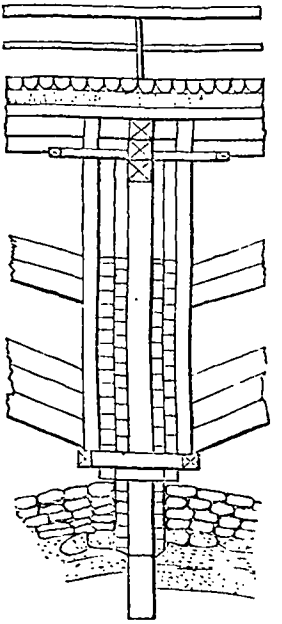


Fig. 2200 FRESINGEN BRIDGE.

Bays and Arches.—When the opening of a bay is not more than 10 or 12 feet, a floor is formed on girders, bearing on the cappings with which the piers are crowned; the piles as well as the girders are then from 12 to 13 inches square: when the distance of the piers is from 17 to 26 feet, pieces of 13 inches square have sufficient strength to carry the weight of the floor, as well as that of carriages; it is, however, always prudent to support them by inclined braces, without which such bays could not last a long time. When the opening of the bays becomes more considerable, the middle of the girders must be sustained by under-girders, supported by braces; this arrangement may be adopted for bays from 26 to 30 feet span, and they may be equally used when they are from 30 to 36 feet, but the girder must then be composed of two pieces framed in the middle, and another under-girder must be placed over the capping, which crowns the piers; a great part of the weight of the bay is then carried by struts, and care is taken to prevent these pieces from yielding by means of one and sometimes two binding-pieces.

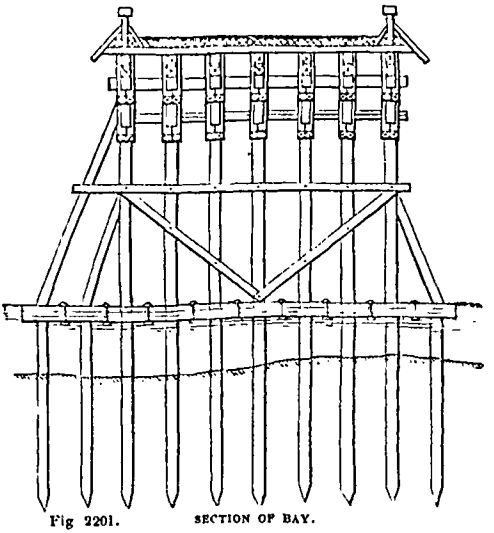


Fig 2201. SECTION OF BAY.

It is rare that the system of under-girders and struts is used for large bays; but in countries where timber from 12 to 14 inches square is easily procured, and not very expensive, this principle may be applied to bays of from 40 to 52 feet span; in which case it is necessary to use two struts, one of which carries the under-girder in the middle of the principal, and the other the extremity of that placed on the capping of the piers: these struts are maintained by two binding-pieces; the under-girders are united to the upper, the extremities of which are screwed together very tightly. If the opening of the bay were as much as 65 or 82 feet, another arrangement might be used by making the under-girders and struts of double or triple pieces; but timbers applied in this manner are far from resisting so advantageously as they might do, the pressures to which they are exposed acting perpendicularly to the length of the pieces, whilst the system might be so disposed that the weight should be distributed in the direction of the length: in this kind of construction the principals must

be multiplied, and very large timbers used, which involves a considerable and needless expense. It is now generally acknowledged that the best method of applying timber in bridges is to form arches with courses of curved timbers bent over each other: this arrangement has been preferred, after several others have been tried, which have proved entirely defective, and the result of long experience is justified by an analysis of the different systems of carpentry in large arches.

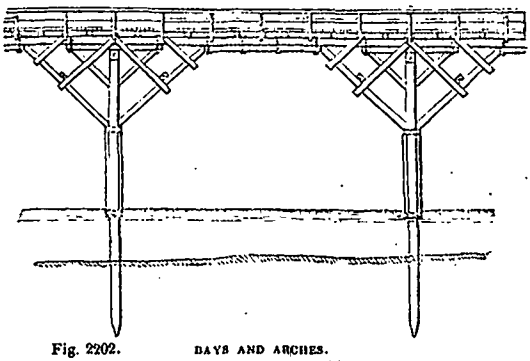


Fig. 2202. BAYS AND ARCHES.

Let A and B, fig. 2174. be two points of support, united by a large principal of carpentry, which principal, besides its own weight, is to carry that of the floor, which may be considered as distributed uniformly throughout its length. The first idea which would present itself is to establish on the two points of support a solid bearing in timber, the form of which shall be such that it resists this double effort equally in all its points, and if we recal the notions which have been given on solids of equal resistance, we shall imagine that this should present nearly the form of $a\,C\,b$, indicated in the figure: let us then observe that if this solid should yield, the fibres situated on the upper surface would be compressed, whilst those situated on the lower would be extended, so that we can trace in the interior of the solid two lines Ca and Cb, which shall separate the compressed from the extended fibres, and that the resistance of the solid exerts itself by means of the pressure directed in the lines Pm, Pn, and of the tensions directed in the lines $P'm'$, $P'n'$, efforts in which this resistance consists solely, and which are the more considerable following each of the lines Pm, Pn, $P'm'$, $P'n'$, as these lines are nearer the surface of the solid, and further removed from the line $a\,C\,b$.

It is easy to draw conclusions from such an example: first, the pieces of which the solids should be formed must be disposed in the direction of the lines, according to which the pressure and the tensions are exerted, for of all the applications of timber, the most advantageous is that where it is pressed or drawn in the direction of its length; it must be observed also, that there is advantage in using the same quantity of pieces, in removing them from each other, in not making the solid full, and in augmenting its height; in short, the effort of the weight which the solid supports may be assimilated to that of a certain weight suspended at the point C, and which decomposes itself into two forces, directed from this point towards the points of support A and B; when the point C is higher with relation to the points A and B, the two components of weight, making a less angle, have a less considerable value, and produce pressures less strong. We are led by these considerations to a system of carpentry represented in fig. 2175., which is that of the bridge of Schaffhausen and Wittingen: the principals of these bridges have the form which would suit a solid of equal resistance, and the timbers are disposed exactly in the direction of the pressures and tensions which they would exert in the solid; but the pieces which would be found in connection with $a\,C\,b$ (fig. 2174.) are suppressed, because, having scarcely any effort to make, they would increase the weight without having any utility: we may remark that the pieces which resist the pressures are in much greater number than those which resist the tensions, which arises from the timber being drawn in the direction of its fibres, and consequently having much more strength than that which is compressed in the same direction. The carpentry of these bridges bears on the abutments, but does not exercise against them any effort which tends to overthrow them; the thrusts being retained by the tensions of the inferior girder, in rendering the abutments capable of resisting the thrusts, we may then, without changing the nature of the system, suppress the girder; this idea leads to the arrangement represented fig. 2176., which is that of the bridge of Kandel. A slight modification in this arrangement gives the combination represented in fig. 2178., which is that of the bridge projected for Lyons; this latter has an advantage over the preceding, because the braces united and subjected to each other form a rafter, and resist much better than when they are isolated, above all, if each of them were to be only of one piece; but this advantage has its inconvenience, for the effort of the weight of the bridge may be considered as that of several weights attached to pendant binding-pieces; in the systems, figs. 2175, 2176. the efforts of the weights suspended to each binding-piece is carried back towards the points of support, and maintained almost entirely by the inclined piece, which abuts at the upper extremity

of the binding-piece, for this weight separates at this extremity into two forces, the one acting in the direction of this piece, and the other in the direction of the beam, and does not tend to make the other struts, which are held by the binding-pieces, yield; all these struts then support only longitudinal pressures, whilst in the system fig. 2176., besides the longitudinal pressures, which are the same as in fig. 2174., the inclined timbers have also to support transversal pressures, since the weight carried by the binding-piece then decomposes into two forces, the one acting in the direction of the great rafter, and the other perpendicular to it. This observation leads to a new modification: as the timbers yield less easily as they are shorter, there must be an advantage of substituting for two inclined timbers a system of three pieces, and although these pieces, making more obtuse angles, cause the weight to be decomposed in stronger longitudinal pressures, more must be gained by the diminution of their length than is lost by the effect of the augmentation of their pressures; thus we obtain the system fig. 2177., which is that of the bridge built by Palladio over the Cismone: in placing, as in fig. 2178., four inclined timbers instead of three, their strength would be augmented, and by thus multiplying their number and diminishing their length, we should have pieces too short to bend, as seen in fig. 2179., and which could only yield by crushing; this is the arrangement for the arches projected by Perronet for the bridge of the Salpetriere, and for those executed at Lyons in that of the Mulatière. In order clearly to show where these last systems are wrong, we shall make some observations on the nature of constructions in carpentry, which naturally find place here.

Whatever may be the combination, in constructions of carpentry the object should always be the transmitting of certain efforts to points of support, by means of a system of levers, subjected one to the other: now we can distinguish in such a system two different equiliburiums, which we shall designate as *Equilibrium of Position*, and the *Equilibrium of Resistance*. The first takes place when the efforts exercised on each lever are so combined with their respective situations that the system does not tend to produce any movement: it is that which forms the objects of statics, of which science teaches us to regulate the conditions. The *equilibrium of resistance* consists in making each lever, which in statics is considered as an inflexible line, have the necessary force for the resistance of the pressures exercised in it; the conditions of this latter equilibrium are the object of the theory of the resistance of solids, and, according to what we have already described, we can always express these conditions with sufficient exactness in constructions of oak.

A system of levers may be maintained in repose by two different means; first, it may be disposed in such a manner that the conditions of the equilibrium of position should be exactly satisfied; secondly, the levers should be so subjected to each other by framing, or by auxiliary pieces, as binding pieces or braces, that it should be impossible for them to change situations with regard to each other as long as the resistance of this framework is superior to the efforts which tend to make the form of the system vary: in this latter case we are not required to satisfy the conditions of the *equilibrium of position*; the system must be regarded as formed by one single piece, and the equilibrium of resistance should alone be taken into consideration. If these ideas be applied to wooden bridges, and the system represented in fig. 2179. be taken, having only regard to the weight of the carpentry and the pavement, the levers may be placed in the situation which suits the equilibrium of position, so that they do not tend to any change of form under the load: but we must remark, that the equilibrium will often be found deranged by the passage of carriages; and secondly, that this not being stable, the slightest derangement would involve the falling of the bridge, whence we may conclude that in the system of levers which compose the principals of a bridge, the equilibrium of position can never be exactly attained: it is then necessary that these levers should be subjected and framed to each other, and that at each articulation the framing should be opposed to their various angles with a force equal to that which produces the variation, according to the effect of the weight; thus the system of the carpentry of a bridge must necessarily be in the second of the two cases already stated. The consideration of the equilibrium of position can never be employed, but to assure ourselves that the framing of the articulations has the force necessary to oppose every change of form; this indispensible condition fulfilled, the system changes its nature; it should be regarded as forming only a single piece, and its resistance valued in consequence.

In examining the principles of figs. 2174, 2175, 2176., we see that in whatever manner the load is distributed, it does not tend to make any change of form, and among the different framings of carpentry, that which has the figure of a triangle is the only one which can have this property; we ought, then, to carry every other system to this, by properly fortifying the articulations, with the exception of that of the summit, so that, whatever may be the arrangement of a principal, its two halves may be considered as two rafters made of a single piece, which at the summit abut against each other; it is an indispensable condition in order that the system should have stability, and no bridge can subsist if this condition be not fulfilled.

In the system of two inclined timbers abutting against each other, it is easy to imagine that the load will separate in pressures in the direction of their length, following two lines drawn from each side of the summit of the principal to the springing; the resistance of these timbers must make an equilibrium to these pressures, and in order to appreciate this resistance, we must consider the timbers as placed upright, and loaded vertically with a weight equal to the pressures. According to this consideration, it is evident how disadvantageous it is that the two halves of a principal should be divided into a great number of articulations, forming so many points of rupture, leaving them no resistance but that which arises from the strength of the framing; it may be easy to give to the framings at each articulation sufficient force to render the system invariable in form, but, as experience has proved, it is very difficult, and even impossible, when the number of levers is considerable, to fortify them sufficiently to procure for each half of the centre a resistance capable of making equilibrium to the pressure which it exercises in the direction of the length: it is for this reason that the systems figs. 2178, 2179. become more disadvantageous as the number of the timbers augments, and terminates by being entirely impossible of execution.

A more solid combination is obtained by disposing inclined timbers, as seen in fig. 2180., in polygons, some of the angles of which answer to the middles of the sides of the others, because if each half of the arch yielded to the pressures which exert themselves from the summit to the springings, not only the framing of the articulations would bend, but the timbers would break in the middle of their length: we must observe that the courses of the inclined timbers not being solidly framed, touch by a very small number of points; a certain flexion may therefore be produced in the whole without each piece sensibly bending; this may happen, should each binding-piece diverge a little from its position, so that the pieces of the polygon situated on the side of the concave face are not shortened, and those of the polygon situated on the convex face are not lengthened, as they would be, on account of the flexion, if they were perfectly united. It is impossible to execute the notches of the binding-pieces with the perfection necessary to prevent this diverging from taking place: thus the system fig. 2180., although very preferable to that of fig. 2179., is far from perfect; the system fig. 2180. was that which Perronet used for the centres of stone bridges. But if, instead of forming the timbers with straight pieces, which can only touch each other at their extremities and in the middle of their length, the whole of which may yield together without each piece in particular being obliged to bend, we use, as in fig. 2181., curved pieces in juxta-position, united and tightened by binding-pieces and bolts, the joints of the extremities of which do not unite opposite to each other, the nature of the system will be found totally changed, and it will receive a very great improvement, for the centre (fig. 2181.) cannot bend without all the pieces of which it is formed yielding: the strength of the framework of the extremities of these pieces no longer

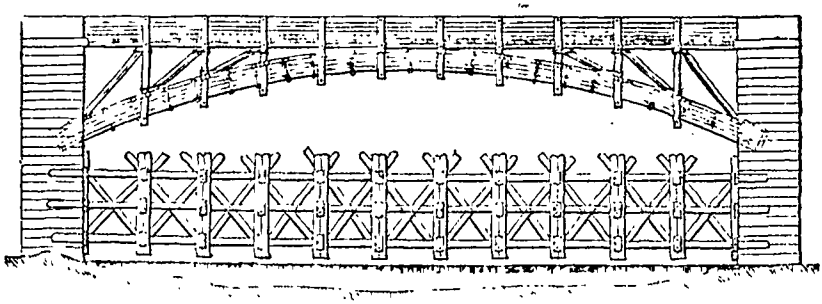


Fig. 2203. BRIDGE FORMED OF CURVED TIMBERS.

opposes itself alone, to the flexion of each half of the centre; the resistance presented by the timbers is a second obstacle to the flexion, more powerful than the first, rendering all bending impossible, if this resistance be sufficient, even if we discard all consideration of the manner in which the framework of the ends is executed.

Arches formed of bent timbers have been adopted for some of the viaducts constructed on our railways, and where sufficient caution has been taken to prevent too much motion from their elasticity, are found to answer very well: the reparation of such bridges is difficult, should any of the timbers exhibit decay; but this disadvantage has been overcome in some instances by making the bolts and straps that hold the curved timbers movable, so that one timber can be taken out without disturbing the others, which lie above or below it.

The disposition fig. 2181. offers, with regard to the force with which each half of the centre resists the longitudinal pressure exerted upon it, the same resistance as the system fig. 2176.; it is equally invariable in form with the latter, and much more advantageous,

as the curve given to each rafter leaves nothing to fear from the transverse pressure to which it is submitted, and there is even no necessity to consider these pressures.

Fig. 2203. represents an arch projected according to these principles for an opening of 132 feet; the principals are at a distance of 6 feet 6 inches from centre to centre; the arch is composed of four courses of curves, tightened by bolts, and so placed that their joints do not meet, some being opposite the others; it carries the floor by means of pendant binding-pieces, which it appears more proper to place vertically than perpendicularly to the curve, and it may be admitted as a general principle, that each piece should always be placed exactly in the centre of what it supports; these pendant binding-pieces are held by horizontal binding-pieces placed on centres, which prevent the spreading out of the principals; courses of vertical and horizontal binding-pieces should never be at more than 16 feet apart.

When the opening of the arch is considerable, the movement of carriages, and sometimes even the action of the wind alone, occasions oscillations in the horizontal direction, which injure the carpentry, and might become very dangerous; the greatest care should be taken to prevent this. If an arch bend in the direction of its width, the horizontal binding-pieces, which were at first parallel between each other, would become normal to the curve which the arch would have taken; they will then have changed position with relation to each other; thus the flexion of the arch will be prevented, if pieces are so disposed as to maintain these binding-pieces in their respective positions; in the half-plan represented in fig. 2203., braces are placed for this purpose in the interval of the courses of binding-pieces.

In the oscillations of an arch, the entire system of its carpentry may participate in the movement, or it may only be partial; for example, the floor may to a certain point move independently of the arch; still it is very important to oppose these effects; there are therefore placed between the first course of pendant binding-pieces, near the springing, inclined struts which secure the union of the floor and the arch, and it appears that this disposition would give to the arch all the solidity and stability which could be desired; it is scarcely necessary to observe that the framing of all these pieces should be secured by bolts, without which the union could not be obtained.

It is requisite to allude to the manner in which the thrust of the arches in carpentry, of the kind we have just indicated, should be considered, and on the settling, of which they are susceptible. If timber did not suffer any compression, and if the execution of the work could be sufficiently perfect for no voids to remain in the framing, and all the pieces could bear exactly one against the other, there could be no settlement; and the force of the timbers being regarded capable of resisting the load, no flexion would be produced; the centre would then be as a single piece placed upon two supports, and would have no thrust; this perfection in the quality of the materials, and in the execution of the work, not existing, it happens that the moment an arch is placed and left to itself it has a tendency to settle: if this movement could operate freely, and the chord of the arch elongate without obstacle, until the framework was tightened, the settling would stop, and the arch would then have no more thrust; but it is always retained by obstacles, which do not permit the chord to be thus elongated, which obstacles necessarily experience a certain pressure; the most simple manner of valuing this pressure is to assimilate the arch of carpentry to a wall of stone, and to examine the horizontal thrust which it would produce, according to its weight and the relation of the yielding at the opening; we shall thus have, not the true value of the thrust of the centre, but a limit below which this thrust always remains, and according to which the dimensions of the piers and the abutments may be regulated. Although the arches of carpentry be confined at their springing, and their chord not being able to lengthen itself the summit cannot sink; they experience a slight settlement, analogous to that of a vault in stone, and to which regard must be had in construction. According to the observations of M. Wiebeking, by representing c as the opening of an arch, and f as its fleche or settlement, the lowering at the middle, expressed in inches, is given by the formula $0{\cdot}02\,\frac{f}{c}$; but we must remark that these observations were made on bridges of fir timber; for centres in oak the settlement should be less considerable. This formula gives the settlement immediately after building, but it increases from the effect of the alteration of the timber.

Floors and Parapets. — Floors of wooden bridges are constructed in various ways; formerly they were almost always covered with a pavement placed on a bed of sand; but it has been ascertained that a very considerable weight was the result, and that the damp produced on the planks tended to make them rapidly perish, as well as the girders on which they were carried; it is therefore preferable to cover them with a false floor, which also prevents them from being injured by the wheels of carriages, and can be renewed as often as necessary.

Fig. 2204. represents the section of a floor disposed to receive a pavement; it is formed by timbers, from 7 to 8 inches square, slightly notched at the meeting of the main timbers,

to which they are attached by iron pins, and the spreading out of which they prevent; the intervals between are filled up by planks, of from 3 to 4 inches in thickness, which

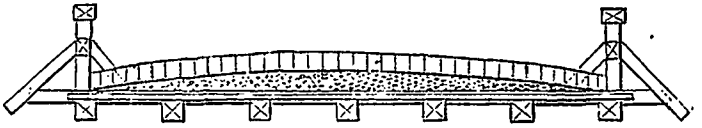


Fig. 2204.

are also nailed; these intervals are generally 6 feet 6 inches, and care has been taken to prolong the pieces, and to place at their extremity a tenon, on which a brace is framed, which consolidates the posts of the parapet, and is prolonged a little further, to prevent the water from remaining in the framework; the posts are also strengthened by another brace, also framed into the main timbers; they are kept together in the length of the bridge by two courses of horizontal rails, one of which, placed on their heads, is laid so as to cap them: within and against the foot of the parapet are planks called guards, which keep in the pavement and sand. It may be remarked that in this floor the main timbers are entirely covered either with joists or planks: there is therefore a constant dampness, and in demolishing ancient bridges, it is constantly observed that the upper parts and the interior of the main timbers are entirely perished, whilst at their

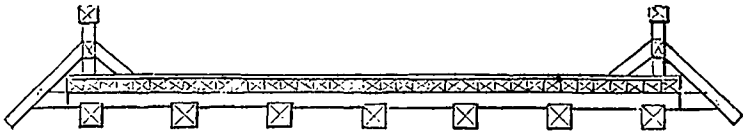


Fig. 2205.

exterior extremities they appear quite sound: this essential defect has been avoided in fig. 2205. The platform of boards is carried on joists from 9 to 10 inches square, at about 8 feet apart: the planks should then be placed lengthwise on the bridge, but the linings with which they are covered are laid transversely, for the purpose of preventing the feet of the horses from sliding on the wood: not only has this latter floor the advantage of allowing the air to circulate round the principal bearers, but it also permits of the principals being removed further apart. Sometimes it is usual to substitute iron balustrades for the wooden parapets on timber bridges; they are composed of upright standards, which should traverse the joists of the floor, and the brestsummers of the principal, on which they bear by means of shoulders secured by screws; these uprights are stiffened by consoles, and their intervals filled up either by rails which traverse them in the middle, or by irons dingonally placed.

It has been proposed, in order to preserve the floors of wooden bridges, to cover the planks with plates of lead and copper, and it appears that the greater duration produced by this precaution will compensate for the expense, or the wooden floors might be entirely omitted, and the main timbers covered with a plate of lead, the edges of which should be lapped one over the other.

During the middle ages throughout Europe, as nas been already stated, numerous timber bridges were constructed, generally supported by one or two rows of piles, forming a pier, united by several horizontal binding-pieces, and strengthened by inclined struts: such piers were placed from 15 to 25 feet apart, and protected by sterlings covered with planks, the intervals between the piles being filled in with stone or chalk, and a capping of timber placed on them, on which the girders which carried the platform rested.

Considerable improvements have since been made in constructing wooden bridges, and almost every country has had its peculiar system: the abutments, and often the piers, are formed of stone or brick: where the streams are narrow, a simple platform laid on timbers of the requisite scantling for the bearing is sufficient; for an increased width struts are added, and trusses of various descriptions.

Foot Bridges of the simplest construction have the beams laid across the opening without any struts; for a span of 15 or 16 feet, a depth may be given to the principal bearers of 15 inches and a breadth of 8 inches; these may be laid about 2 feet apart, and covered with plank: or two piles may be driven, inclining inwards, coupled at the head by transverse beams mortised and pinned into them; they may be further strengthened by horizontal pieces at different portions of the height; on the transverse beams may be laid as many joists as are required for the width of the bridge, for which, if of an ordinary kind, two will be suffioient; the parapets may be strutted on to the pro-

jecting parts of the transverse beams, which are mortised on to the piles, and thus be firmly supported.

Foot Bridge over the Clyde at Glasgow. — The nine bays are carried on pairs of piles, distant about 42 feet apart, and under each longitudinal beam is a second, over the heads of the piles, which extends 10 or 12 feet on each side, and acts as a corbel; this being firmly bolted through gives considerable strength to the main timbers, which are further strengthened by a truss formed in the parapets of the bridge.

Timber Bridges with longitudinal timbers laid across the stream, and supported at every 15 or 20 feet by a row of piles driven into the bed of the river, have the capping placed upon the heads, and supported by side braces; additional strength is given by

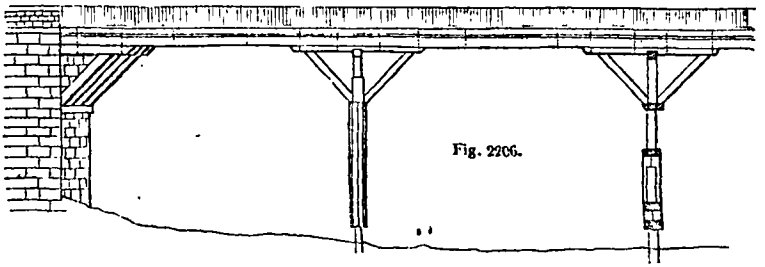


Fig. 2206.

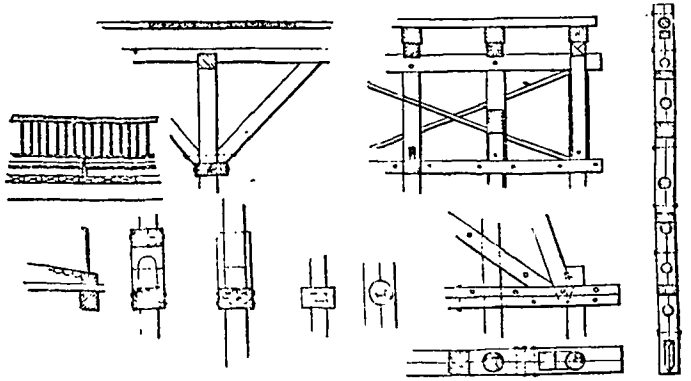


Fig. 2207.

bolts passing through the longitudinal timbers; cross-planking forms the road or footway, over the ends of which another longitudinal timber is laid, and iron bolts are passed through the whole to unite them together.

In narrow foot-bridges the piles may be driven slanting, and united at the top by a capping, which, projecting considerably on each side, serves for the introduction of a strut to strengthen the side fence or railing.

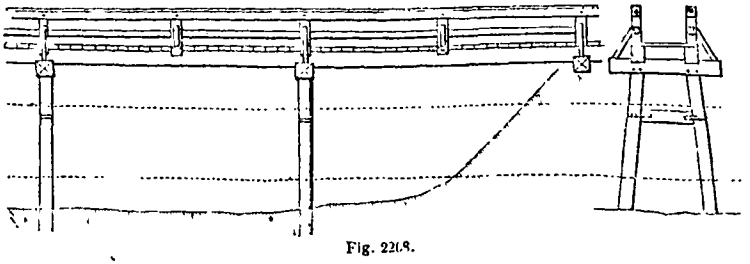


Fig. 2208.

The piles may be driven further apart when the struts are used to discharge the weight of the platform; a horizontal timber is bolted from one pile to the other, which serves as an abutment to the struts, and unites the piles which form the piers more firmly.

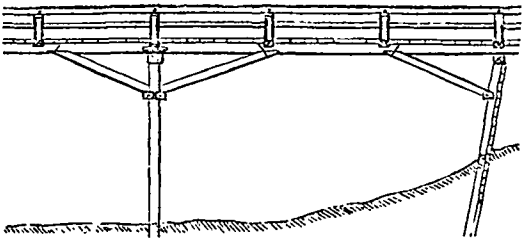


Fig. 2209.

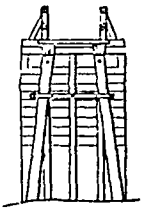


Fig. 2210.

Such a bridge as the last may be made of very considerable strength by introducing under the longitudinal timbers an additional thickness, against which the two struts abut; and

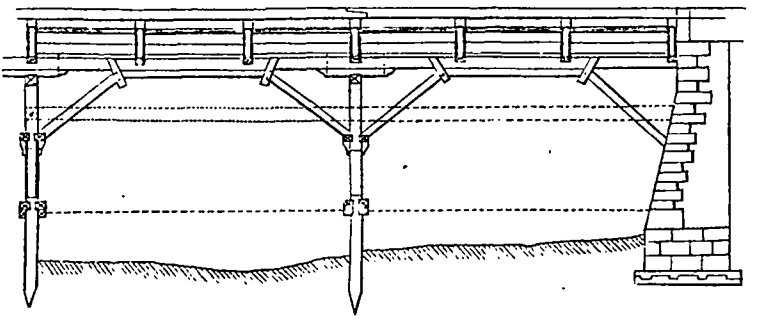


Fig. 2211. BRIDGE OVER THE DANUBE, NEAR ULM.

taking the precaution of having a hard material between the ends of the timbers, where their fibres are likely to penetrate, and iron bolts to secure the whole together: abutments of brick or stone are always preferable when they can be constructed.

Where the bearing is upwards of 40 feet, additional strength is obtained by the introduction of stout pieces of timber under each beam; these may be secured by iron pins; so strutted, they are capable of sustaining considerable weight.

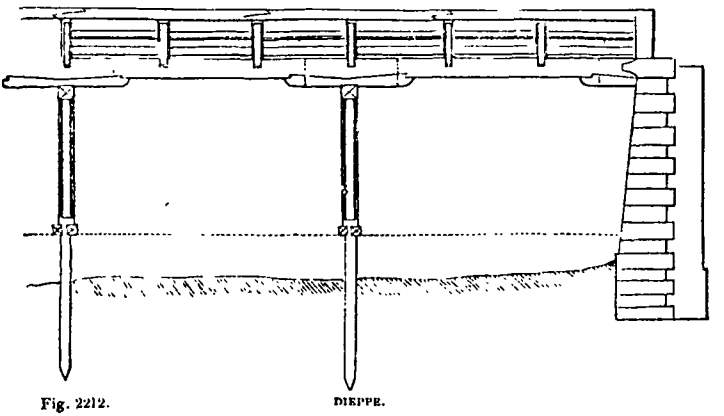


Fig. 2212. DIEPPE.

In many instances it is found that the construction of a timber bridge is rendered less difficult when the piles that support the platform are in two lengths, or that the first are driven into the bed of the stream, and cut off a little below the level of the water: upon the heads of these lower piles rests a plate, laid in the direction of the current, and on which the piles that form the piers are secured: should these require any reparation, it can be readily effected without the aid of the pile-driving machine.

A bridge for carriages of 30 feet distance between the piers may be constructed upon this principle; but as greater stability is required, another strong piece of timber may be put under the principal bearers, and strutted as shown: the clear width is 15 feet between the parapets.

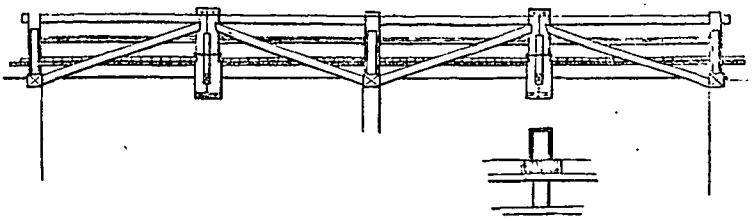


Fig. 2213. VRACH IN WURTEMBERG.

Horse Bridge at Vrach in Wurtemberg exhibits a simple form of truss, which answers for the parapets of the bridge; the distance between the piers is about 35 feet, and the clear width between the parapets is 7 feet 6 inches.

There is considerable ability displayed in the arrangement of the timbers of the several bridges over the arm of the Necker, which are so disposed as to form the railing or parapet; a kind of construction productive of the greatest economy, at the same time allowing the entire space beneath the platform of the bridge to be open for the passage of boats, and unimpeded by the torrent, which may occasionally require the entire opening of the bridge for its passage: where timber is floated down a stream from the forest to a port for its embarkation, there should not be the slightest impediment presented, which would be the case if the framing of a bridge were continued down to the water's edge.

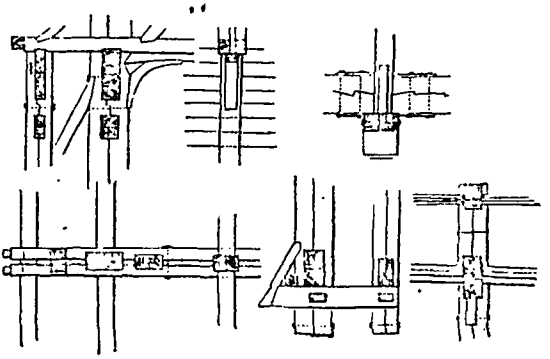


Fig. 2214. DETAILS OF THE BRIDGE AT VRACH.

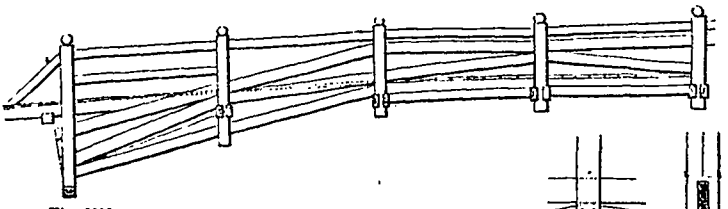


Fig. 2215. NECKER.

That over an arm of the Necker, built by M. Ezel, is of the same character; the distance between the piles is not less than 38 feet, and the clear width between the parapets is 17 feet.

St. Clair, over the Rhone at Lyons, constructed by M. Morand in the year 1775, shows great skill in the application of the timbers: it has 17 bays, varying in width; that in the centre is 45 feet, and they proportionably decrease on each side, the extreme openings being only 33 feet. The first piles that were driven to form the piers were cut off level with low water, and on their tops was laid a timber platform, into which the posts which supported the bridge were framed: the bridge was 36 feet in width, and the piers consisted of 13 posts in a row, each composed of two pieces of timber strengthened and

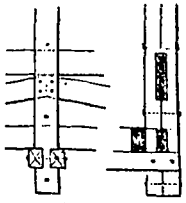


Fig. 2216.

protected by horizontal pieces, one under the braces, and the other immediately above the level of the river, through which passed iron bolts that tied and secured the whole pier together: the 13 double posts, which formed the pier, were capped, and on them were laid as many longitudinal timbers, which formed the supports to the floor of the bridge, and an additional piece or two was bolted to them, in the middle of their span, with struts and pendant braces.

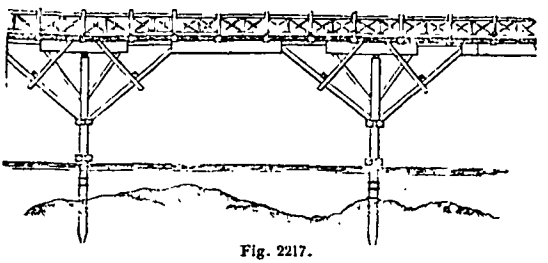


Fig. 2217.

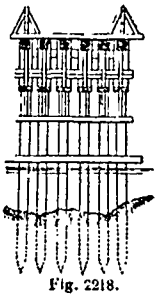


Fig. 2218.

Palladio's Bridge over the Cismone.—This was executed over a river at the foot of the Alps, between Trent and Bassano; its length is about 108 feet; it is divided into six equal openings. The river being rapid and subject to floods, bringing down trees and stones, it was not thought advisable to fix any piles in the current: the timbers mutually support each other, and the whole system is strongly framed together.

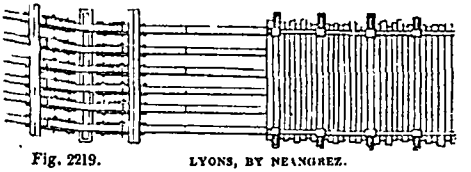


Fig. 2219. LYONS, BY NEANGREZ.

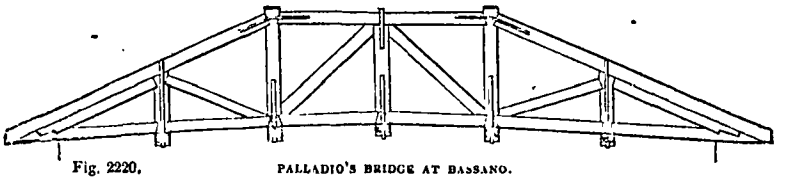


Fig. 2220. PALLADIO'S BRIDGE AT BASSANO.

Five girders, 12 or 13 inches square, disposed at equal distances, are laid at right angles to the length of the bridge, or about 18 feet from centre to centre: these appear to have no support; the girders being a little longer than the width of the bridge, carry the principal timbers or joists which cross the river, on which the planks are laid which form the floor. The five girders do not lie level; the three in the middle are elevated a little above the other two, so that the sill which lies upon them, and into which the king- and queen-posts are framed, is also out of a level; the part at which the two outer sills abut against that in the middle being elevated, the whole takes the form of a segment; the upright posts or *coloneili*, which are framed into them, are also bolted through and secured on the under side: all the struts,

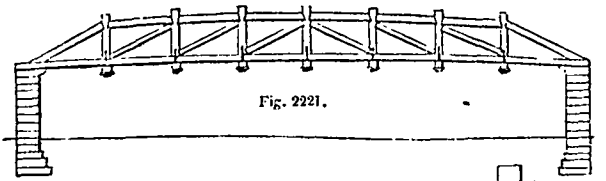


Fig. 2221.

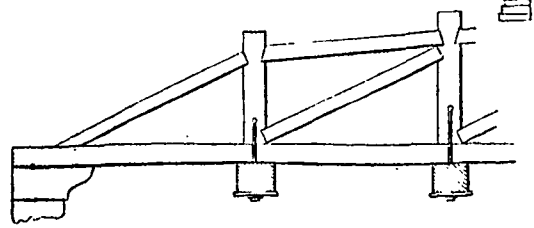


Fig. 2222. PALLADIO'S BRIDGE.

straining-pieces, and other portions of the trusses on each side are out of timber 12 inches by 9; these trusses form the parapets, and are secured by iron straps and bolts at the extremities; they are capable of supporting a considerable weight without any sensible deflection; their height is about 16 feet, and the principle seems to have been that of a series of triangles, which are not liable to any change of form. The abutments are of stone, and the height of the parapets or trusses are nearly ¼ of the entire span.

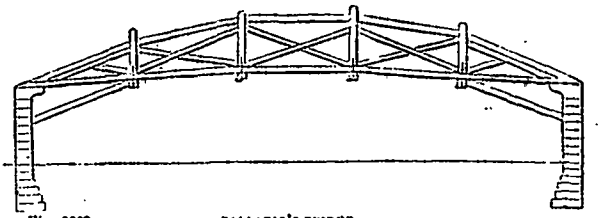


Fig. 2223. PALLADIO'S BRIDGE.

Fig. 2223. is another of Palladio's bridges, supported like the preceding by a truss on each side; its length is divided into eight bays by transverse girders, suspended by stirrup-irons and bolts from the posts framed into the head and sill of the truss; these posts are braced strongly, but their strength is not equal to those of fig. 2222.; the centre bays are liable to drop, as the bearing is too great: in this construction the first bays from the abutments should have four depths of sill, the second three, and the third two, leaving the two centre bays with only one; thus the ends of the bridge would appear to rest on corbels gathered over from the abutments, or these additional timbers might be laid side by side; this would require the transverse girders to vary in length, that they might comprise and tie them together. The height of the trusses is about one-tenth of the span.

Fig. 2223. is a portion of a polygon of five sides, with four king-posts and braces, like a St. Andrew's cross; the outer heads are doubled, and struts are added to throw the weight of the first bay on the abutments: the transverse girders are carried by the king-posts, to which strong stirrup-irons and bolts are attached: the side trusses of this design, which form the parapets of the bridge, are about one-ninth of the span in height.

The parapets in fig. 2224. may be considered as consisting of eleven voussoirs, each formed of posts, strongly braced by diagonal timbers like a St. Andrew's cross: the transverse girders are held up by iron straps, as in the other examples, and the height of the framing of the parapets is not more than one-twelfth of the span.

Of the four designs left us by Palladio the first combines the best arrangement of the timbers with the greatest solidity: in the last there is an appearance of great strength, but when we take into account the shrinking to which the timber is liable, it is evident that the voussoirs would be subject to great change from the compression they must undergo when heavy loads passed over: motion destroys in the course of time the tightness first given to the framing, and subsequently the nice balance of such a timber construction: that design braced like a St. Andrew's cross, and which partakes of the arc of a circle, would not so readily alter its form, and would preserve its firmness and solidity for a length of time.

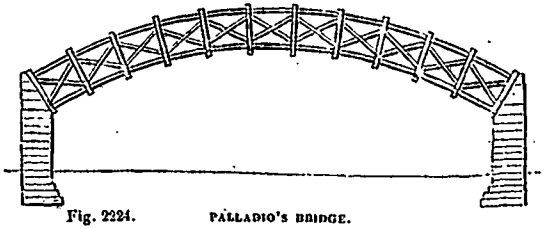


Fig. 2224. PALLADIO'S BRIDGE.

Bridges of Palladio's construction could not be adopted where a greater width of carriage-way than 14 or 15 feet was required; the transverse girders would require upholding by additional longitudinal trusses, if the width were increased.

Bridge at Bassano, at the foot of the Alps, over the Brentar, was also erected by Palladio: the river is 180 feet in width, and there were five bays of equal widths.

Palladio gives the following directions for the construction of the bridge fig. 2241.: "The banks must be first fortified with pilasters; then one of the beams that forms the breadth of the bridge must be placed at some distance from them, and the beams that form the sides be disposed upon it, which, with one of their heads, must lie upon the bank, and be fastened to it; upon these, directly plumb with the beams for the breadth, the colonelli are fixed, fastened with cramps of iron, and supported by braces secured to the heads of the bridge; the other beams are then placed, leaving as much space between each as there is between the first and the bank; in the middle of the breadth of the river there must be

a colonello or post, in which the centre braces meet, and on the upper part of which must be fixed other braces, uniting with the next colonello, tying all together, and forming with the braces in the head of the bridge a portion of a circle less than a semicircle.

Foot Bridge, over the canal of Gooda, in Holland, 45 feet span, is of very simple construction; it is formed of curved timber, framed to resemble the segment of an arch. There are two sets of ribs, on which rest the longitudinal bearers that carry a planked floor, 4 feet 6 inches clear width between the parapets or railing: the posts into which the horizontal rails are mortised, by an additional length unite and hold together the curved and straight timbers, on which the platform rests.

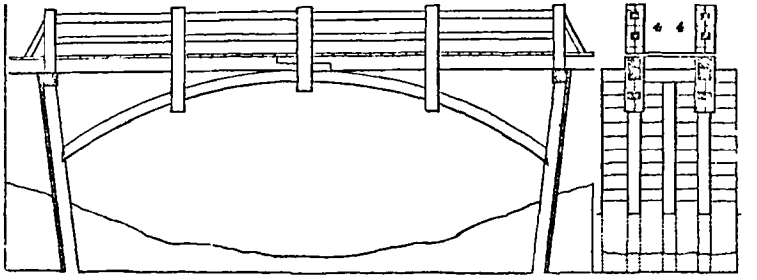


Fig 2225. GOODA IN HOLLAND.

Another Foot Bridge in Holland, over the canal at Utrecht, of the same span, shows greater strength; its clear width between the railing is 5 feet 6 inches; struts are introduced, held in their positions by couples or pendant binding-pieces.

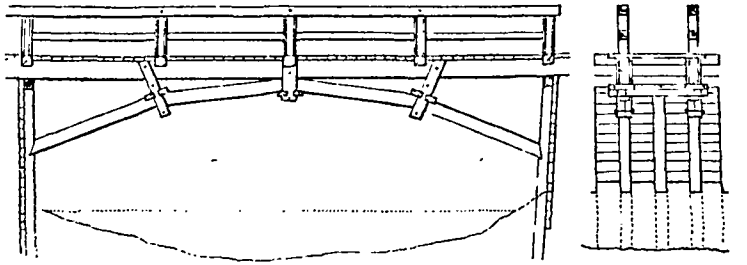


Fig. 2226. UTRECHT CANAL. Fig. 2227.

Mulatière Bridge at Lyons, over the Saone, has eleven openings; the centre is 57 feet 6 inches, and the others gradually diminish to 49 feet span. The piers are each formed of two rows of piles, driven parallel to each other: three horizontal pieces of timber bolt them together above the water: on the tops are framed abutments like those of Trajan's bridge, receiving the thrust of the principal timbers: each opening has an

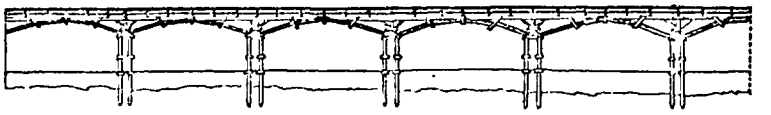


Fig. 2228. MULATIERE AT LYONS

arch, formed of four sides of a polygon; each of these sides consists of two pieces of timber, framed or scarfed together, one being cut like the teeth of a saw, and the other indented to receive it: after these are fitted they are securely bolted together. Where the ends of these pairs of timbers unite and abut against each other are pendant binding-pieces, to hold up and secure them to the principal longitudinal timbers which carry the platform: the error of this kind of construction arises in part from the pendant pieces maintaining a constant humidity, which is communicated in time to the polygonal pairs of timbers and the framed abutments, when a partial decay takes place, and a settlement follows.

The timber bridges at Kingston-upon-Thames, Walton, and many others in England, ware constructed upon this principle, and were constantly requiring repairs.

Bridge over an arm of the Necker, at Wurtemberg, has a width of carriage-way of 14 feet, and a clear span of 58 feet; it is queen-post trussed, and strongly strutted against stone abutments.

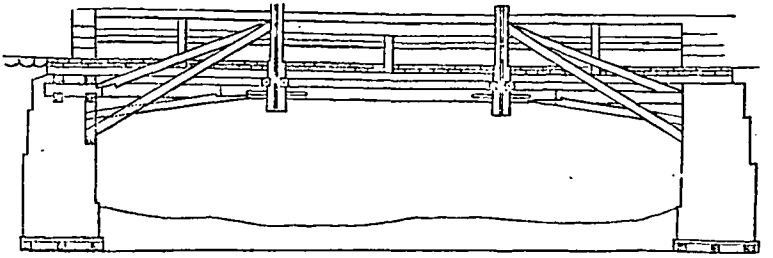


Fig. 2229. BRIDGE OF NECKER, AT WURTEMBERG.

This kind of bridge does not require much skill in framing the timbers, nor any other application of mechanical principles beyond that of strength; the squared timbers are placed across the stream or canal parallel to each other; on these are laid stout planks or transverse pieces to carry the roadway, which is made either with earth or gravel, and kept in its place by stout planking at the sides. The principal timbers are prevented from sagging by the introduction of the two upright posts in the railing, which hold up that portion of the platform most liable to drop by means of struts and a stretching-piece put together in the manner of a queen-post truss; and if the abutments are maintained in their position and prevented from

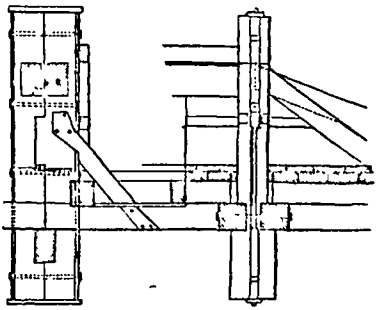


Fig 2230. BRIDGE OF NECKER.

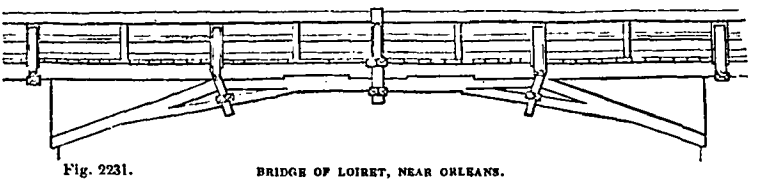


Fig. 2231. BRIDGE OF LOIRET, NEAR ORLEANS.

sliding, and the ends of the timbers protected from decay, such a bridge will endure for a considerable length of time. As timber of a uniform scantling and of the proper quality

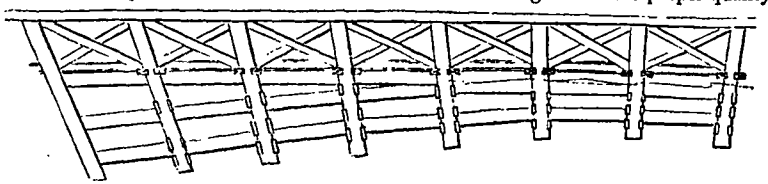


Fig. 2232. SCHONENBERG CANAL.

for bridge-building is difficult to obtain beyond the length of 50 feet, these constructions must be limited to that span.

A horse bridge, 6 feet 6 inches wide, over the Loiret, near Orleans, with a span of 60 feet, has its longitudinal timbers bearing on a very strong truss.

Over the canal of Schonenberg, near Brussels, is an occupation or horse bridge, 8 feet wide and 70 feet span, formed of pendant binding-pieces which diverge from a centre, against which timbers are strutted polygonally, in three rows at a distance from each other, all held

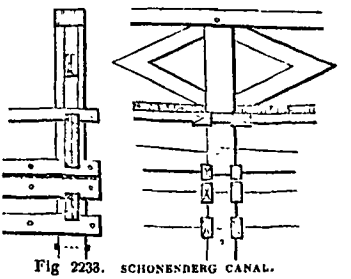


Fig 2233. SCHONENBERG CANAL.

in their places by transverse ties; the parapets are formed by the introduction of a St.

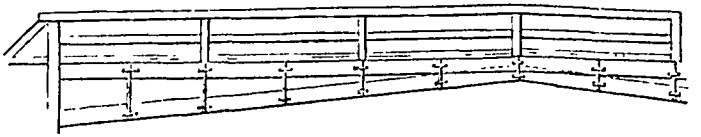


Fig. 2234. BRIDGE OVER THE BRUSSELS CANAL.

Andrew's cross between the pendant binding-pieces, and making a very strong truss, by uniting the whole together like an arch, which cannot materially alter its form as long as the stone abutments maintain their solidity.

Over the canal at Brussels is a horse bridge, 83 feet span, of very simple construction, and which would have been much more solid, if perpendicular posts or blocks had been introduced into the triangular space formed by the inclined timbers which support the platform of the bridge.

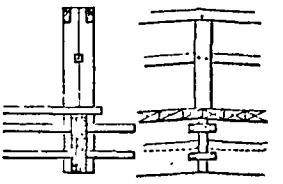


Fig. 2235. BRUSSELS CANAL.

Over an arm of the Necker, which is 93 feet wide, is a light horse bridge 8 feet span; two sets of king-post trusses in the parapet strengthen the main longitudinal timbers,

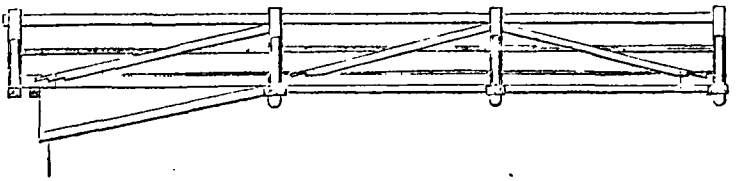


Fig. 2236. HORSE BRIDGE, NECKER.

but from the disconnection of the middle pieces of framing, this arrangement of the timbers must be very defective.

Notre Dame at Cahors, built by Sganzin, has a clear width of carriage-way of 17 feet, and a span of 95 feet, formed of one polygonal arch, the versed sine of which is between a fourth and a fifth of the span; its composition is defective, from being composed of too many pieces, which must be subject to a considerable shrinking, and seriously derange the whole

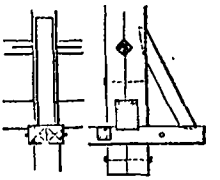


Fig. 2237. NECKER.

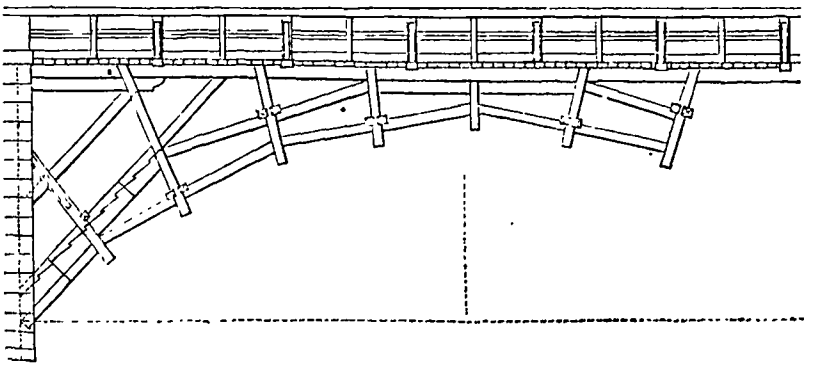


Fig. 2238. NOTRE DAME AT CAHORS.

framing; when the timbers are thus shortened, the angles of their junction necessarily become more obtuse, and in consequence are likely to open, particularly when heavy loads pass over them. This cannot be considered any great improvement in construction over the bridge of Mulatière at Lyons.

Bridge of three Arches over the Loire, each 92 feet span, with a clear width of carriage-way of 27 feet, and a versed sine of 8 feet 6 inches; they are well framed

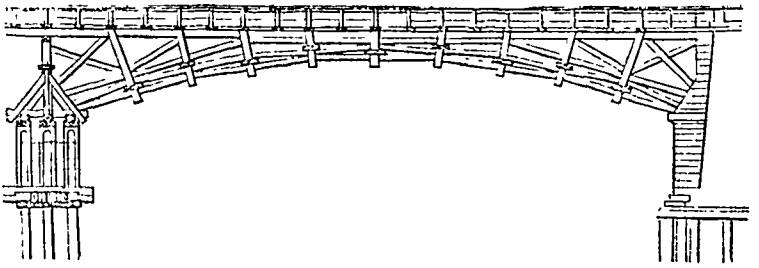


Fig. 2239. BRIDGE OVER THE LOIRE.

together; nine pendant binding pieces radiating to a centre maintain the polygonal timbers that form the arch in their position; and where these pendant timbers increase in length towards the abutments, they are again strutted securely.

Over another arm of the Necker is a horse bridge 90 feet span, and a clear width of way of 10 feet, in which the pendant pieces are the posts that form the parapet.

The king-posts in this bridge are placed perfectly perpendicular, and the side braces ap-

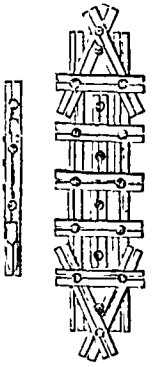


Fig. 2240.

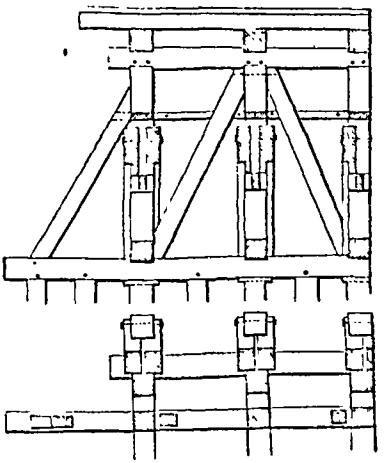


Fig. 2241. LOIRE.

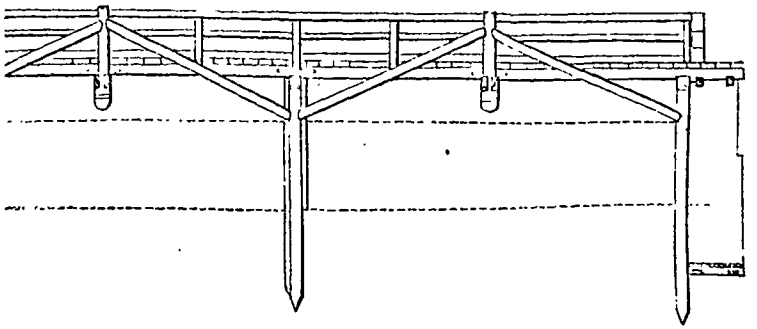


Fig. 2242. BRIDGE OF VRACH IN WURTEMBERG, OVER AN ARM OF THE NECKER.

plied to their sides spread to the full extent of the opening, having their abutments against each other on the piers: a nail is introduced between the tops of the several king-posts, which serves as a straining piece, and prevents them from approaching each other. The floor is carried in the middle of the span upon a stout transverse bearer, suspended to the ends of the king-posts by means of iron straps and bolts. So long as decay is prevented, and main timbers preserve their form, this construction is durable and economical; but if the heads of the piers are suffered to break the tie by which they are held in their perpendi-

cular position, the struts will lose their abutments, and the balance between the timbers which constitutes the entire strength of the bridge will be destroyed; an iron tie would insure greater stability, and might be introduced across the stream, under each side of the platform, without changing the disposition of any of the timbers.

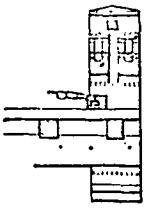


Fig. 2243.

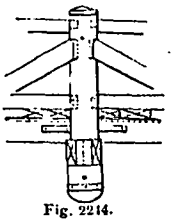


Fig. 2244.

In some of the timber bridges on the continent, where the oak platform that sustains the road has been in a state of decay, and requiring constant repair, stone pavement has been substituted, laid from bearer to bearer, and in some instances iron plates perforated with holes, to allow the water to pass through; but the additional weight produced by either of these is so considerable, that it is a question whether any benefit has been obtained.

Bridge at Tête in Picardy, erected by M. Coffinet; its span is nearly 126 feet, and its versed sine scarcely an eighth of the span.

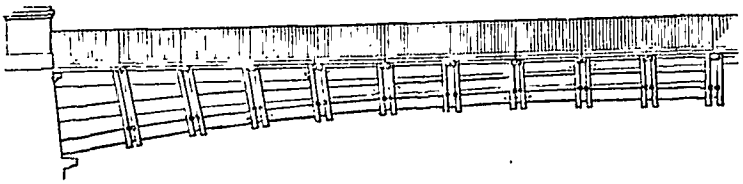


Fig. 2245. BRIDGE AT TETE IN PICARDY.

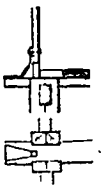


Fig. 2246.

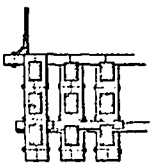
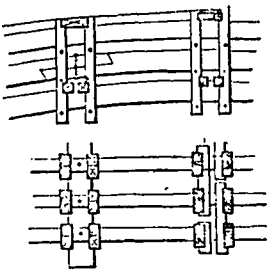


Fig. 2247.



BRIDGE AT TETE IN PICARDY. Fig. 2248

Perronet's Timber Bridges were upon the principle of the polygonal arch; the spans of the arches were equal; the framing of the timbers that carried the roadway extended

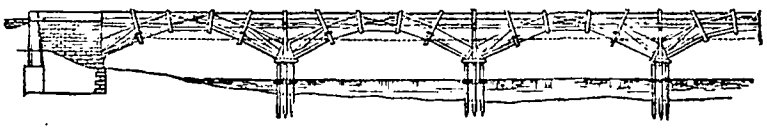


Fig. 2249. PERRONET'S TIMBER BRIDGES.

through the parapet or railing on each side of the bridge, by which means the form of a

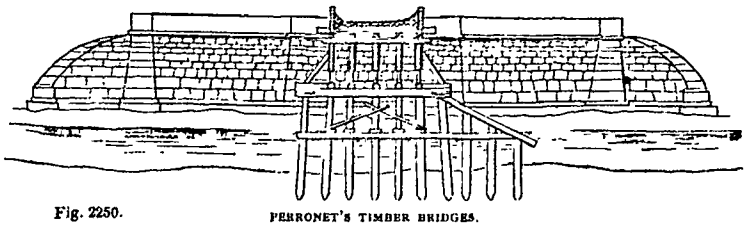


Fig. 2250. PERRONET'S TIMBER BRIDGES.

polygon was given to the several struts and supports: regarding each side of the polygon that abutted on the piers as a simple truss, and proportioning the timbers to the duty they had to perform, there perhaps could not be a more simple arrangement, or one that offered, with the same amount of material, greater strength; but the quantity of framed work and the liability to decay in the several joints have occasioned this system to be abandoned.

Bridge of St. Clement, over the Durance, with a span of 115 feet, was an early instance of the application of the suspension principle. The length was divided into nearly three equal parts; in the middle division an additional timber was placed under the main longitudinal beam, to which it was firmly bolted, and the division was held up by four radiating posts, which were kept in their position by strong straining pieces introduced between their heads, and by a St. Andrew's cross framed in between them; the centre framing formed almost a single mass, and was kept from sinking by diagonal struts resting on the abutments; the lower of the two, from their inclination being so flat, could not be very effective, and the principal stress in consequence must have been thrown upon the others, which abutted against the top of the suspendant posts; these diagonal struts had also two pendant binding-pieces and cross struts, to assist in carrying the platform of the bridge, and prevent their springing. After the timbers had shrunk, the whole weight of the bridge must have been thrown upon the upper pair of struts, which abut against the pendant binding-pieces.

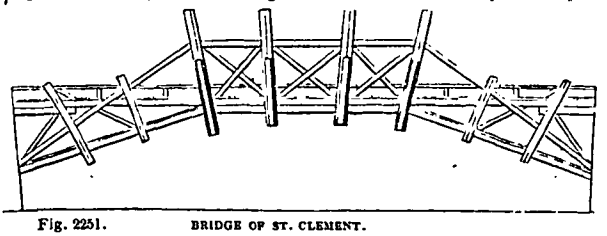


Fig. 2251. BRIDGE OF ST. CLEMENT.

Bridge at Savines has a clear width of way of 10 feet, and a span of 75 feet; it is also upon the suspension principle, but the timbers are more simply arranged; the abutments

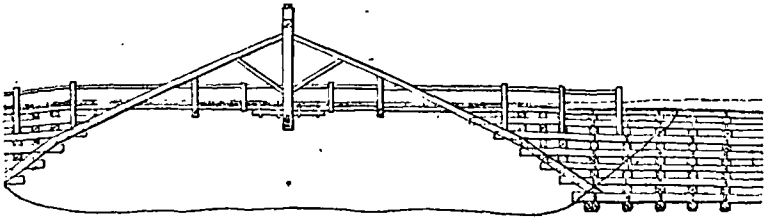


Fig. 2252. BRIDGE AT SAVINES.

are of timber. In the centre is a post 16 feet in height above the platform of the bridge, into the head of which are framed two diagonal struts or principals, one on each side, for the purpose of suspending it; this post is strutted to the principals, and holds up the middle of the longitudinal timbers of the bridges, as a king-post sustains the tie-beam of a roof; other pendant pieces are attached to the inclined principals, and shorten the bearing, by holding up the longitudinal timbers at regular distances: all those bridges formed of braces diversely inclined are defective in strength, and consequently in duration.

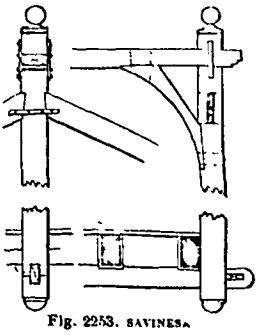


Fig. 2253. SAVINES.

Bridge of Schaffhausen was constructed in the year 1757, by John Ulrich Grubenmann, a village carpenter of Tuffen. It was formed of two arches, one spanning 172 feet, the other 193 feet: this bridge, so celebrated for its beautiful carpentry, was destroyed by the French troops in the year 1799. The abutments as well as the middle pier were of stone; the longitudinal timbers or plates were formed by uniting two strong pieces together, *en cremaillere*, which were supported underneath by four inclined struts on each side: above the platform six other inclined struts on each side supported another longitudinal series of beams; double binding pieces hanging perpendicularly from the upper longitudinal beams, under the eaves of the roof, held these struts in their proper position, and prevented their springing. The transverse

girders or beams which supported the floor of the bridge were suspended to the perpendicular binding-pieces, at a point immediately under the lowest longitudinal beams; the top longitudinal beams were composed of five thicknesses throughout the five middle divisions of each set of framing, and four at the two outer. Every precaution was taken to prevent the framing from yielding in the centre or middle of the arches; the whole of the timbers were judiciously applied, and perfectly succeeded; the platform or floor was made with a double thickness of planks, the lowest being nailed to joists, and the others crossing them at right angles." This bridge was not constructed in a straight line;

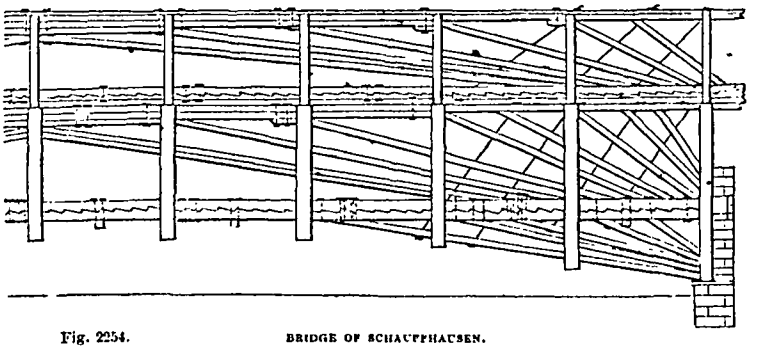


Fig. 2254. BRIDGE OF SCHAUFFHAUSEN.

the middle pier being placed about 13 feet up the stream, which it was supposed would give the structure greater strength and stability, but it trembled considerably, even from the weight of one passenger passing over it. It was only once repaired during the 42 years that it stood, though the oak timbers which rested immediately on the abutments and pier, from not being thoroughly seasoned and sufficient air allowed to circulate around them, went early to decay; to replace these defective timbers, screw-jacks were employed upon scaffolding supported on piles, to raise this ponderous piece of carpentry in a mass, when others were introduced.

Bridge over the Limmat, near the Abbey of Wittingen, was also erected by the same carpenter, assisted by his brother John Grubenmann, and burnt soon after that of Schaffhausen. It consisted of one opening, 390 feet span, with a rise of 43 feet, and was a more solid and even superior piece of carpentry, all the timbers being well proportioned

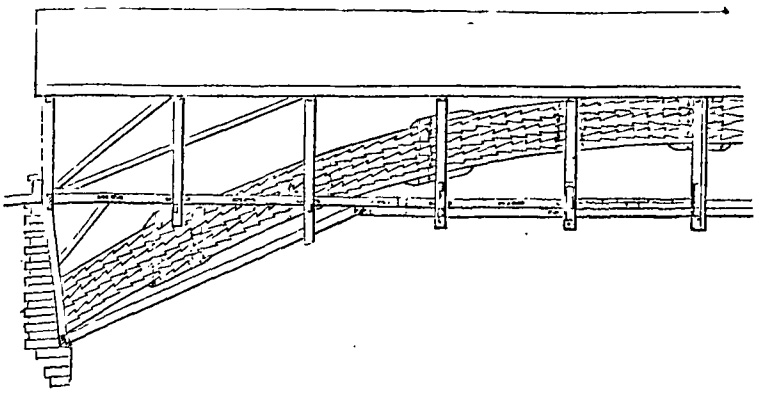


Fig. 2255. BRIDGE OVER THE LIMMAT, ONE-HALF.

to the great opening. The floor was sustained by two longitudinal beams on each side, put together one over the other *en cremaillere*, and supported at each abutment by inclined struts, the lowest of which were doubled: level with the plate of the roof was a second longitudinal timber, which formed the principal support to the whole structure; this consisted of a single thickness at the parts nearest the abutments, but increased in number as it approached the middle, where it was composed of four thicknesses. Struts of various inclinations were placed between these longitudinal timbers, and the whole

maintained in their places by twenty-four pendant vertical binding-pieces, put at a distance of about 16 feet from centre to centre. The ridge of the roof of this bridge, as well as that of Schauffhausen, was supported in the centre by inclined struts, which carried the weight

Fig. 2256. BRIDGE OVER THE LIMMAT.

nearly to the extremities. This is the greatest span ever executed with timber, and its radius of curvature, or curve of equilibrium, was about 600 feet.

Bridge at Zurich has a bearing of 128 feet, and is extremely simple in its construction; the floor or platform of the bridge is sustained upon longitudinal timbers which increase in

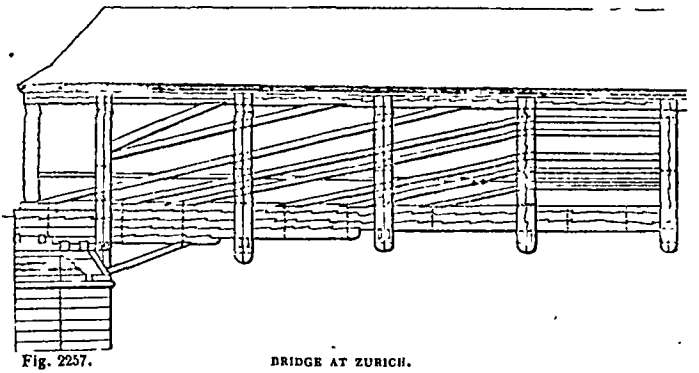


Fig. 2257. BRIDGE AT ZURICH.

thickness towards the abutments; they are sustained in a level position by eight pendant binding-pieces, attached to another longitudinal series of beams, which are strutted on to the abutments by eight variously inclined struts on each side.

Bridge at Ceslingen, over the Necker, upwards of 210 feet between the abutments, is another fine example of similar construction.

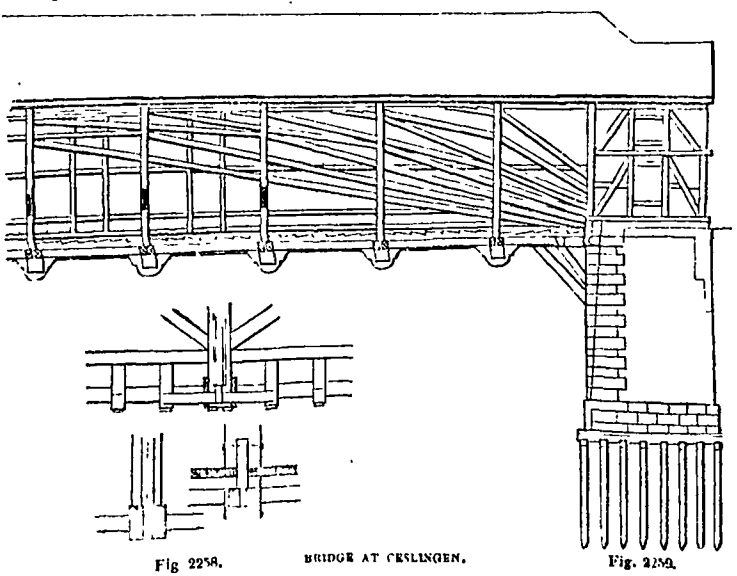


Fig 2258. BRIDGE AT CESLINGEN. Fig. 2259.

Bridge at Berne, over the Kundel, was constructed by Joseph Ritter, in the year 1764; the distance between the abutments is 166 feet; their height has allowed

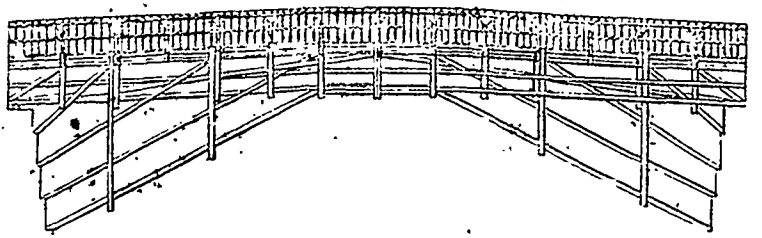


Fig. 2260. BRIDGE AT BERNE.

the struts to be placed in a more judicious position, and to be inclined almost parallel with each other; there are five on each side, of fir timbers about 11 inches square; the longest are about 75 feet. The longitudinal timbers which carry the floor are highest in the middle, where they are strengthened with an additional thickness, bolted to the upper one from below: into the longitudinal timbers are framed transverse girders at every 18 feet, which are again diagonally braced; over them are placed the joists and timber platform.

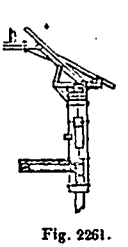


Fig. 2261.

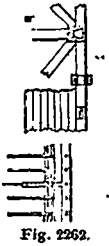


Fig. 2262.

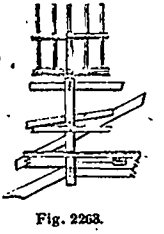


Fig. 2263.

Bridge over the Saone at Lyons, designed by M. Gauthey for an opening of 164 feet, was upon the foregoing principles: it was intended that this bridge should have had three sets of longitudinal timbers, one passing through the middle, which would have permitted of two independent thoroughfares. Bridges constructed upon a different plan have now

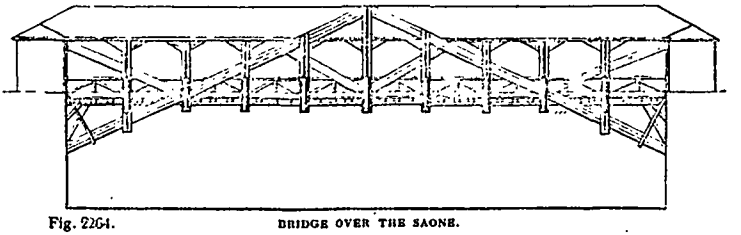


Fig. 2264. BRIDGE OVER THE SAONE.

succeeded to the celebrated examples just described: the art of construction had at one time attained, it was thought, the greatest possible perfection, and Schaffhausen, Wittingen, and others were named as works of carpentry not to be surpassed; but, renowned as they were, the binding of timbers into arched forms has been found not only stronger, but more economical and durable.

In the "British Carpenter," by Price, published in 1765, a method is described for forming curved ribs to support the roadway of a bridge. He proposes that they should rise as much as one-sixth of the intended span, and be divided into convenient lengths, suitable to the timber to be employed: for an arch or opening of 36 feet he makes the ribs of oak in five lengths, and 3 inches in thickness, each rib to consist of two thicknesses, and 12 inches deep, the joints alternating in the middle of each length, and the two thicknesses keyed together with oak keys, and he states that two perfect ribs, so formed, would be strong enough to support the roadway.

Chazey on the Ain has a bridge of four arches, each 63 feet 6 inches span, supported by stone piers and abutments, and this is said to be the first erected in France upon the new principle. The platform or floor is supported by several ribs, each of two thicknesses of timber, united by forming the sides in contact, like the teeth of a saw, one entering the other; these ribs are the arc of a circle, and are so secured by iron bolts that they cannot easily spring: pendant binding-pieces, radiating from the centre of the circle, of which the arc is a portion, are attached to the longitudinal timbers which cross the stream, and the spandrills of the arches or spaces between the curved and longitudinal timbers are each filled in with two additional struts bearing upon the abutments.

Bridge of Mellingen, constructed by Ritter, a carpenter of Lucerne, in the year 1794, has an arch of 157 feet span. The two principal timber arches are arcs, equal to the sixteenth of the entire circumference of the circle of which they are portions; they are formed

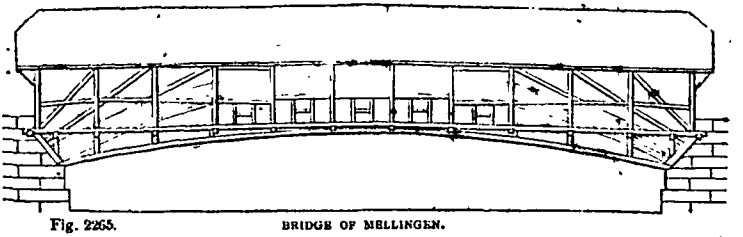


Fig. 2265. BRIDGE OF MELLINGEN.

of six pieces of fir, each 10 inches square: twelve vertical binding-pieces are suspended to them, extending from the plate that carries the roof to the longitudinal timbers which support the platform or roadway of the bridge, and down to another timber arch, of a flatter segment than those already described, formed of single timbers, and, though apparently intended to assist in supporting the roadway, adds very little to its strength, but materially to its weight.

Bridge of Tournous, constructed over the Saone in the year 1801, has five equal arches of 89 feet span, carried on stone piers, 16 feet 6 inches in thickness; they are arcs of circles, one-sixth of the circumference, and each is formed of six ribs composed of three pieces of bent timber, 9 inches in height, and 11 inches in width; the ribs are 4 feet 8 inches from centre to centre; twelve radiating pendant binding-pieces, about 6 feet 6 inches apart, support the longitudinal timbers that carry the platform or road; in the intervals between these is an iron bolt, which passes through the three thicknesses of bent timbers, screws them firmly together, and prevents their springing.

Bridge over the Seine, in Paris, erected in the year 1802, has two arches, each 104 feet span, with a versed sine of 6 feet 6 inches: the two main arches consist of four

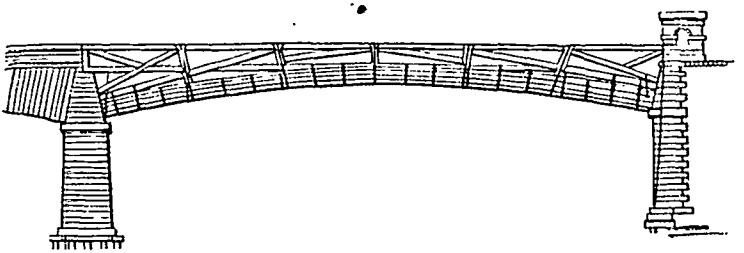


Fig. 2266. BRIDGE OVER THE SEINE.

thicknesses of timber, 10 inches square, bolted together with great care; there are no intermediate principals, although the bridge is 32 feet wide. An arch is thrown across the space between them, continuing the whole length of the bridge, and abutting against the two principal longitudinal arches, which are prevented from yielding to the thrust by a number of iron ties above and below the arch, and crossing from one side of the bridge to the other.

The Timber Bridge at Grenelle was an excellent specimen of an arch of bent timbers supporting the platform: there was another of this kind constructed over the Seine at Ivry, in 1828, by M. Emmery, who published a description of it a few years

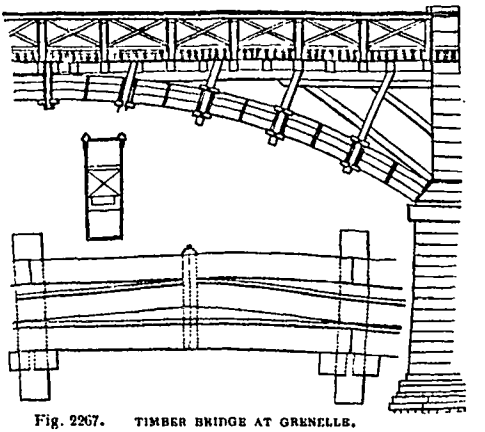


Fig. 2267. TIMBER BRIDGE AT GRENELLE.

afterwards: the span of the arches was about 75 feet, and their rise about $\frac{1}{4}$; they were composed of three bent timbers, the lowest being of a greater depth than the others, and were kept together by the binding-pieces which sustained the timbers on which the platform for the road rested.

The Bridge over the Meuse is 60 feet span, and consists of four arches, a section of two of which is shown in the diagram below, having the longitudinal timbers and springing

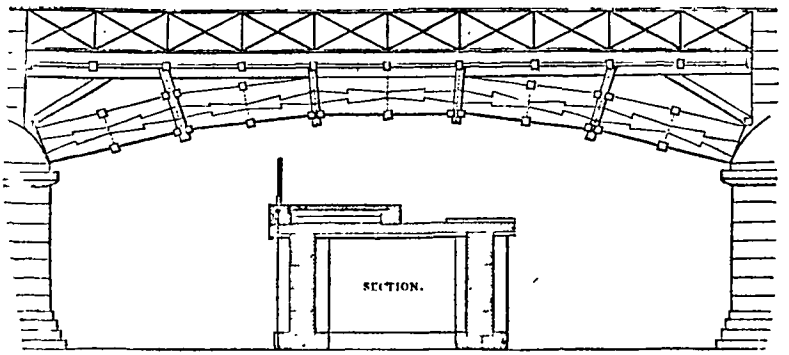


Fig. 2268. BRIDGE OVER THE MEUSE.

plates placed above and below the three bent timbers: the entire width of the bridge being about 28 feet, the distance between the arches was scarcely 8 feet.

Bridge over the Rhone is another example of supporting the roadway on timber arches held firmly by transverse timbers bolted together above and below, into which are framed radiating binding-pieces that abut against the under side of the longitudinal timbers.

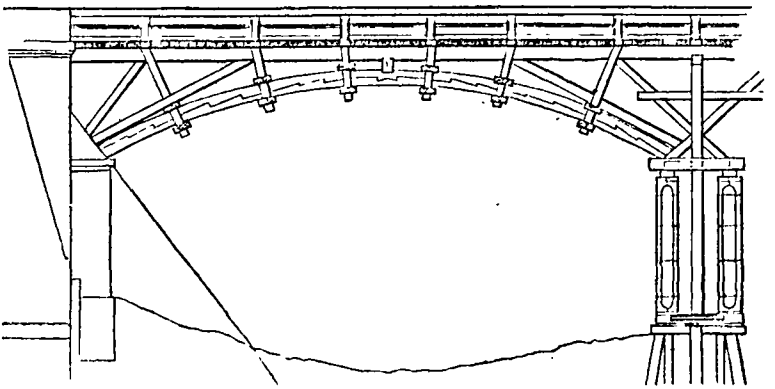


Fig. 2269. BRIDGE OVER THE RHONE.

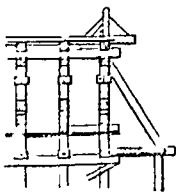


Fig. 2270.

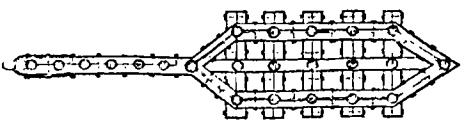


Fig. 2271.

The plans of the piers and section are shown, as well as the contrivance above the piers or protecting them against ice or trees that may be carried down by the river.

Bridge built over an arm of the Necker, at Wurtemberg, about 63 feet span, has the roadway

suspended to the timber arch: this kind of *hang werck*, as it is termed in Germany, is the same as that employed at Feldkirch and Mellingen.

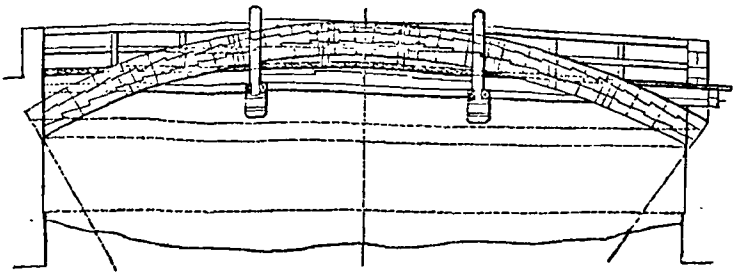


Fig. 2272. WURTEMBERG BRIDGE, ON THE NECKER.

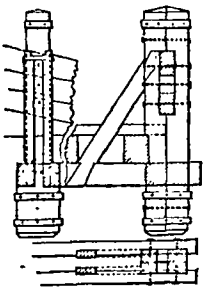
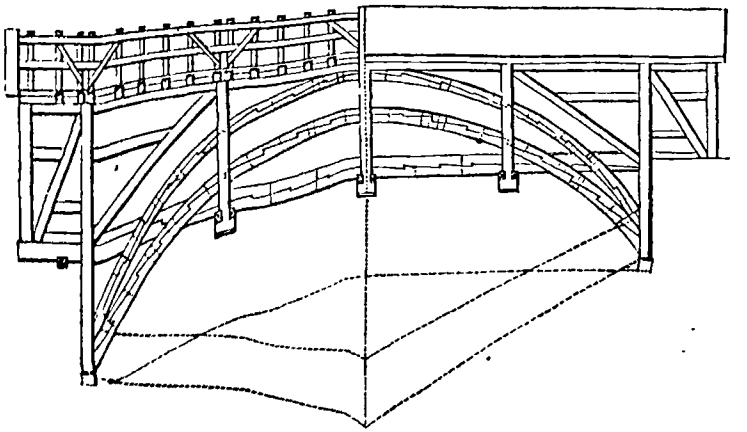


Fig. 2273.

Before the principle was adopted of jagging or notching the three timbers which form the ribs, to enable them more firmly to lock into and abut against each other, it was the custom to build up the arches with courses of solid logs of oak, in length from 12 to 15 feet, and about 16 inches square; those were selected from the forest which had a curve most suitable to the arch to which they were to be applied; and in producing the requisite form the timbers were never cut across the natural grain; they were so laid that their abutting joints did not come over each other, and were afterwards secured together by straps or hoops, which surrounded them at every 5 feet distance. Much inconvenience resulted from this method, and an arch constructed with three bent timbers notched into each other is a rash improvement upon it: in one instance the platform of the bridge was supported by the sides of the polygon, and in the other by the arc of a circle; both required that the abutments should not yield, but the strength of an arch formed with bent timbers is far less likely to be interfered with than that consisting of a number of timbers arranged along the portion of a polygon; for some of the sides lying horizontally, and others perpendicularly, it is not possible to make them all bear equally, and resist the effort occasioned by a load placed on the centre of the bridge.

The Bridge of Feldkirch, on the Rhine, is perhaps one of the earliest constructed upon the principle of suspending the roadway to one or more timber centres or arches; the span is about 65 feet 6 inches: each centre is formed of two timbers, cut and indented so as



BRIDGE OF FELDKIRCH, SWITZERLAND.

to unite closely and firmly together; the carpentry was well executed, all the mortises and tenons cut with great precision, and the whole protected from the weather by a light timber roof.

Bridge at Scurre, on the Suone, is supported upon the ancient stone piers: the arches are 95 feet span, and are formed of five principal ribs, placed 4 feet 9 inches from centre to centre, each composed of three pieces, bent one over the other, each piece being about 10 inches in width and 16 inches deep; the versed sine is 11 feet 6 inches. The timbers which carry the floor are 12 inches by 10, and are supported by inclined pieces, which are not of much utility: the eight pendant binding-pieces are formed out of timbers 9 inches square, and iron bolts and straps are frequently introduced to add to its strength.

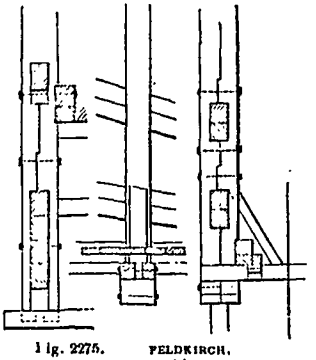


Fig. 2275. FELDKIRCH.

The Bridge at Choisy has five arches supported on stone piers and abutments, the span of which is 67 feet, and their versed sine 8 feet 9 inches: each of the three timbers which form them is 10 inches in width and 12 inches in height; pendant binding-pieces with iron bolts are introduced in the intervals, to secure the bent timbers. The longitudinal timbers that carry the parapets and platform have a double thickness over the piers; on these lie the transverse timbers that support the planking of the floor, which is formed of two thicknesses: this bridge was completed in the year 1811.

M. Wiebeking, director-general of the bridges and roads in Bavaria, has published many designs of bridges executed under his direction since the year 1807, and by him the construction with curved ribs has been greatly improved: instead of using short pieces of timber he employs those of considerable length, and bends them one over the other to suit the curve required; the number of joints is lessened as much as possible, which renders the ribs stronger, and less liable to decay.

The Bridge of Neucettringen, over the Inn, was one of M. Wiebeking's first works where curved ribs were used: it is composed of five arches with stone abutments, the span of which are 102 feet 6 inches, and the versed sine about $\frac{1}{8}$ of their span. The breadth of the bridge is 24 feet 6 inches, and there are but two principals to each arch, each formed of three courses of timbers, one over the other; the courses are 13 inches in height and width: five transverse girders rest on the curved ribs, and occupy the depth between their top and the horizontal timbers that support the floor; those in the spandrills have an extra depth: between the transverse girders, which cross the principal ribs, are struts laid horizontally, and the whole is pinned securely and bolted with iron: into the projecting ends of the transverse girders are framed upright posts, which are strutted and form the parapets.

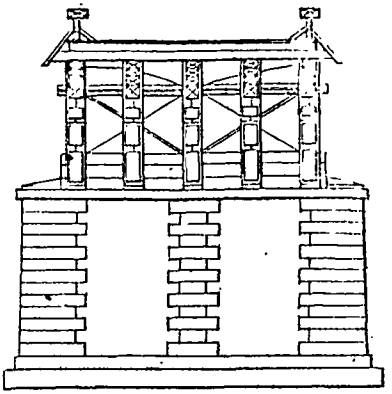


Fig. 2276. BRIDGE OF NEUCETTRINGEN.

In the spandrills, or the space between the curved ribs and the longitudinal timbers which carry the floor, are vertical timbers, called piers of tension; from these issue struts, which are more or less inclined as they are placed farther from the abutments. The abutments of the arches are 10 feet within the face of the masonry; the piers consist of a row of nine piles, the ones inclined, to give the greater stability. Starlings are formed above bridge: all the timbers were well pitched, and the whole was covered with planks externally, which are removed in the fig., to show the construction.

Freysingen Bridge, over the Isar, in Bavaria, was constructed by M. Wiebeking in the year 1808, and consisted of two arches, 152 feet span, with a rise of 11 feet 6 inches, the radius of curvature being 246 feet: the width of the bridge is 24 feet 6 inches; there were three sets of curved ribs in the section transversely; each arch of these sets had three curved ribs, united at seven points by as many pendant binding-pieces, which supported seven ranges of beams laid in the direction of the length of the bridge, with diagonal braces between them, the joists that supported the road being laid across them. The ribs that

carried the road were varied in their curve; the lowest, having the greatest, was formed of three courses of timber, from 13 to 14 inches in thickness, and about 45 feet in length: these timbers were bent by screws made for the purpose, and when curved sufficiently were bolted together.

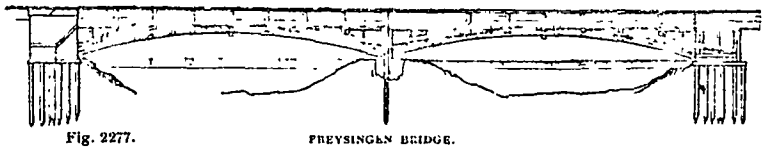


Fig. 2277. FREYSINGEN BRIDGE.

The upper arch or rib was formed of two courses of timber about 15 inches square each; sixty-eight piles, from 30 to 40 feet in length, and 15 inches square, were driven by a ram, the force of which was equal to 1450 pounds, 17 or 18 feet into the ground, to form each of the abutments. The middle pier consisted of nine vertical and two inclined piles, about 17 inches square, and 45 feet in length; on the heads of these was laid a horizontal capping, which sustained the vertical posts, against which the ends of the ribs abutted; the posts were lined with strong oak planking, and the spandrills filled in with beton.

The exterior was cased with planks, and by jointing made to resemble a stone bridge; to preserve the timbers every mortise and tenon was well saturated with hot oil previous to uniting, and small channels for the water were cut in the curved ribs and inclined struts and braces; pitch and tar were applied in abundance to all the principal timbers. After the bridge was completed, one arch settled about 3½, and the other nearly 12 inches, which probably arose from the difference of workmanship; this bridge was destroyed about 1809, since which it has been re-constructed on the same plan.

Bridge of Bamberg, over the Regnitz, constructed by the same engineer, in the year 1809, has one arch, the span of which is 206 feet, and the versed sine 16 feet 6 inches, with a width of roadway of 32 feet: the radius of curvature is 422 feet. The ribs and joists are all of fir timber, and the cross ties and plates of oak: there are three sets of main ribs, one placed in the middle of the width, and the other on each exterior side; that in the centre has three ribs side by side, the middle having at the abutments five beams in depth, and at the crown three; the two other or outer main ribs have but three courses

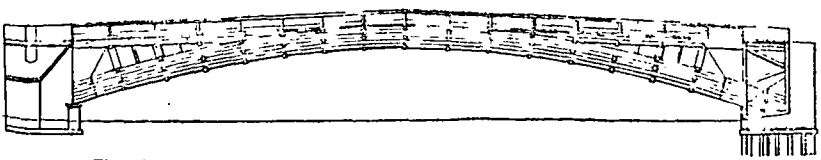


Fig. 2278. BRIDGE OF BAMBERG.

of timber throughout their whole extent: the dimensions of the timbers which form these courses vary from 13¼ to 15¼ inches square; as in the bridge of Freysingen, cross ties are introduced between the main ribs, and the roadway is similarly constructed.

This celebrated engineer and bridge-builder erected in Bavaria many others, upon the same principle to those already described: that at Sharding has a width of roadway of 25 feet, the span of its arches 194 feet, with a rise of 19 feet; another at Augsbourg has its span 114 feet, and the rise of its arch 10½ inches, the radius of curvature being 158 feet; that at Ettringen, over the Wertach, has a span of 139 feet, with a rise of 8 feet, and the radius of curvature 305 feet; that at Irsingen, over the Wertach, 126 feet span, with a rise of 7 feet, and a radius of 285 feet; that of Oettingen, over the Inn, 103 feet span, 6 feet 9 inches rise, and a radius of curvature of about 200 feet; that at Vilshoven, 179 feet span, and 11 feet rise, the radius of curvature being 378 feet; that at Altenmarkt, on the Alz, 140 feet span, 13 feet rise, and 203 feet radius of curvature.

M. Wiebeking has usually given 25 feet for the ordinary width of his bridges, which is sometimes increased to 32, and the rise of roadway is 1 in 24, which is by no means inconvenient; he found that timber bridges would settle, when constructed upon his principle, about 1 foot in 72, so that, to have a rise of 1 in 24 when finished, it must be framed for a rise of 1 in 18. The proportions he gives for the rise of different spans are valuable, as they are entirely the result of his practical observations, unmixed with any theory; he states generally, that a tenth rise is the best proportion, but that for convenience it is better to keep them lower: from 100 to 155 feet span, he makes the rise $\frac{1}{16}$; for 200 feet, $\frac{1}{18}$; 300 feet, $\frac{1}{15}$; 400 feet, $\frac{1}{11}$; 500 $\frac{1}{13}$; and 600 feet span, $\frac{1}{12}$: the greater the span, the greater must be the rise.

Bridge over the Delaware, at Trenton, in New Jersey, in America, built by Mr. Burr, in 1804, consists of five arches of different span, and crosses the river where its width is

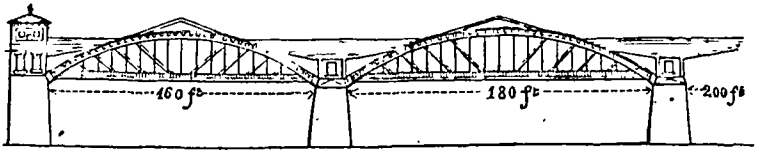


Fig. 2279. DELAWARE BRIDGE.

1100 feet. The arches rise from their chord line, in the proportion of 13 to 100 feet, and they are all segments of circles: there are in the width of the bridge five parallel

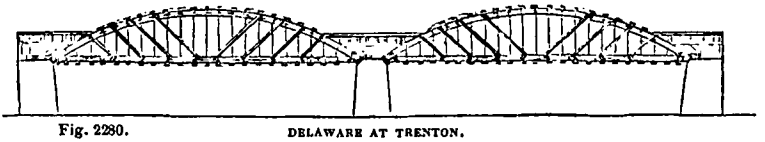


Fig. 2280. DELAWARE AT TRENTON.

rows of these arches; one traverses the middle, two are placed at a distance of 11 feet, and admit carriages between them; the outer are at a further distance of 4 feet 6 inches, forming two carriage and two footways.

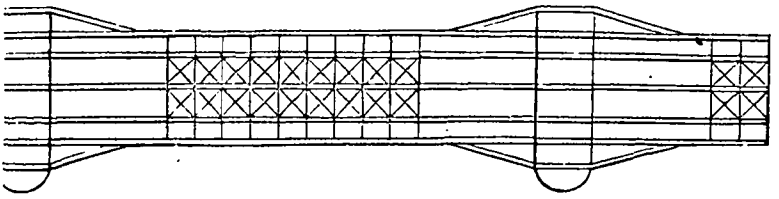


Fig. 2281. PLAN.

The ribs are cut from planks of white pine from 35 to 50 feet in length, 12 inches wide, and 4 inches thick; these planks are laid close together, the joints being broken, and having an equal depth throughout of 3 feet; they are all held firmly together by iron straps: thus a rib is made as strong as one of whole timber, and, to prevent them from

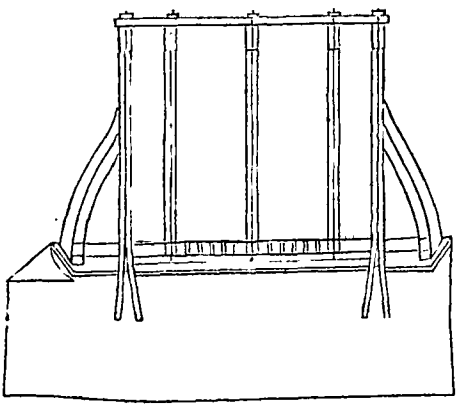


Fig. 2282. SECTION.

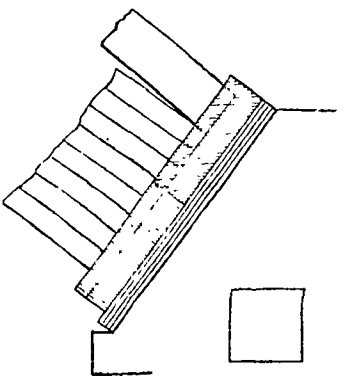


Fig. 2283. ABUTMENTS.

springing, horizontal tie-beams are introduced, from one pier to the other, connected by diagonal timbers with the ribs; these are carried above the spandrills of the arches, which are filled in with diagonal braces; thus the ribs are so strengthened above and below that they cannot easily change their form.

The platform that carries the road is suspended from these five arches by perpendicular iron rods, which hook into eyes fixed on the arches, at a distance of 8 feet apart in the

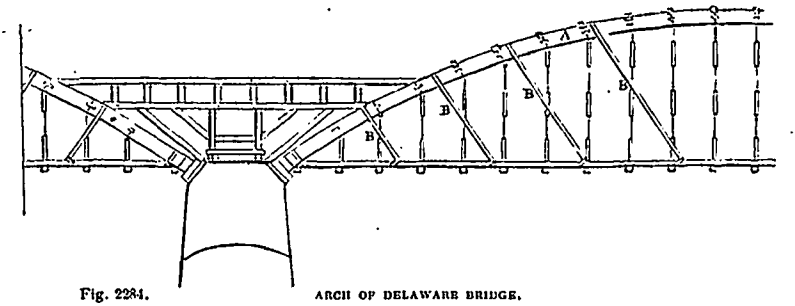


Fig. 2284. ARCH OF DELAWARE BRIDGE.

three middle, and 16 in the two outer arches; stirrup-irons at the lower ends of these rods receive the joists; diagonal braces unite the platform with the tie-beams, and prevent any motion to which it would be subjected; stone piers and abutments carry this ingenious piece of carpentry, and the whole is roofed, to protect it from the weather. Three arches on one side are each 200 feet opening, the fourth 180, the fifth 160 feet, and the versed sine of the largest 27 feet.

The Bridge over the Susquehanna, in Columbia, constructed in a similar manner, was completed in 1834; there are twenty-nine timber arches, each of 200 feet span, supported on two abutments and twenty-eight stone piers. The water-way of this magnificent bridge is 5800 feet, and its whole length, including piers and the abutments, 1¼ mile. There are three sets of timber arches, which allow of two passage ways for road and railway carriages, the whole breadth being 30 feet.

The Timber Bridge over the Portsmouth rivers in America, built after the designs of Mr. Bludget, has but one arch, with a span of 250 feet. The timbers are placed at a distance apart equal to twice their own depth: there are three concentric ribs; the middle carries the floor of the bridge; they were selected from crooked timbers, so that the fibre might run nearly in the direction of the curves, and are connected together by pieces of hard and incompressible wood, with wedges driven between, the ribs being mortised to receive them; thus the three ribs are kept at a regular and parallel distance from each other. Each rib is formed of two pieces, laid side by side, about 15 feet in length; they are all disposed in such a manner as to break joint, the end of one piece of timber coming in the middle of the length of the other, which is near it; their ends all abut with a square joint against each other, and are neither scarfed nor mortised, the two pieces of timber being held together by transverse dovetail keys and joints: all the timbers are admirably united, and freely exposed to the action of the air; any piece may also be removed, in case of its requiring reparation, without injury to the rest of the structure.

The only defect in its construction is that of mortising through the principal ribs so frequently for the purpose of admitting the wedges, which renders them not so strong, and more susceptible of injury by compression; the keys and wedges effectually fill up the holes cut to receive them, therefore it is supposed that the strength is not so much impaired. This bridge would receive additional strength by the introduction of braces, which would connect the three ribs together, and if of iron more firmness would be given to it.

Richmond Bridge, in America, is a fine example of lattice-work, as adapted by Mr. Town to a span of 78 feet up to 150 feet; and as there is no lateral thrust, and materials of small scantling are required, this system has been much adopted on the railroads: the lattice framing is composed of fir planks, about 3 inches in thickness and 12 inches wide, arranged so as to lie across each other at right angles; at the points of intersection they are united by oak treenails 1¼ inch in diameter, which pass entirely through them. The depth of the lattice-work is proportioned to the span, and is about 9 feet 6 inches when the former is 78 feet.

In the bridges constructed upon this system there are but two ribs, one under each side of the roadway, connected together at every 12 feet by cross timbers, between which are diagonal braces. The lattice frames are usually placed in recesses prepared for them in stone abutments; at Philadelphia a lattice bridge was constructed, which extended 1100 feet, resting on ten stone piers; and on the New York and Haerlem railway another, 736 feet in length, with only four stone piers.

One of the chief points to be considered in the construction of large timber arches is the lightness and elasticity of the material; for when a heavy load is placed near one of the

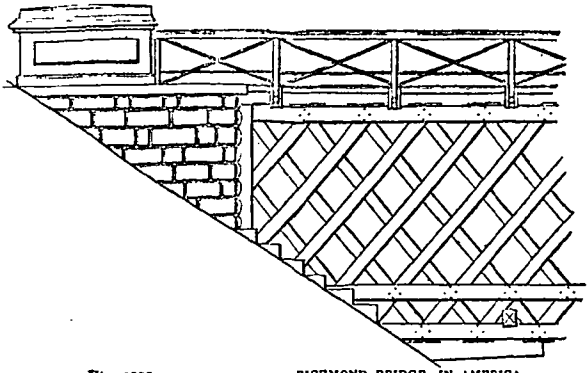


Fig. 2285. RICHMOND BRIDGE, IN AMERICA.

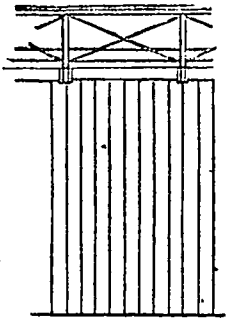


Fig. 2286.

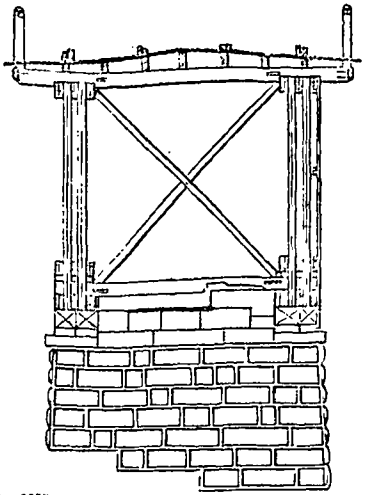


Fig. 2287. TRANSVERSE SECTION, RICHMOND BRIDGE, AMERICA.

abutments, it causes a depression at one part and an elevation at the other, which, although apparently trifling, disturbs the equilibrium, and racks the framing in such a manner as to be highly detrimental to its stability. Cross-framing, by halving scantlings together, and attaching them strongly to a top and bottom beam, has long been practised, and found to constitute a very effectual truss: but wherever they are used, they should be covered by a roof, or protected from the effects of the weather; for a framing composed of a great number of pieces would have its form greatly changed by any trifling contraction or shrinking of the several parts. The horizontal timbers are more subject to such an effect than those which are placed vertically, or that receive their pressure in the direction of their length; consequently, in lattice bridges, great care is requisite to have that portion of the timbers well seasoned upon which the abutments of the several struts are secured.

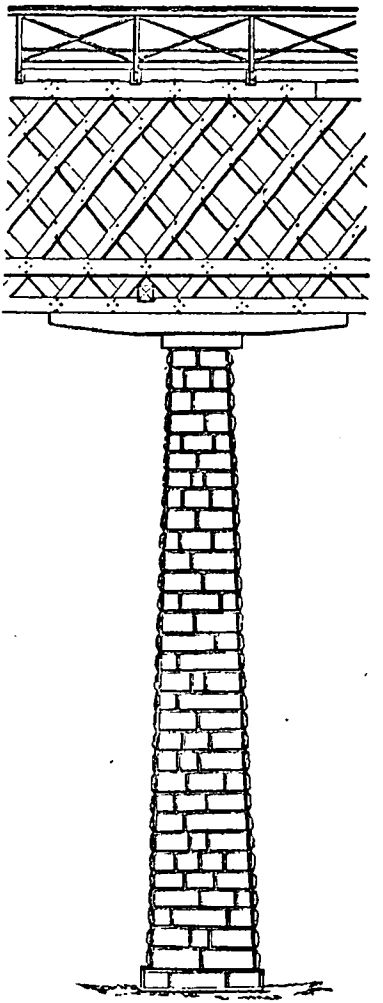


Fig. 2288. RICHMOND BRIDGE, AMERICA.

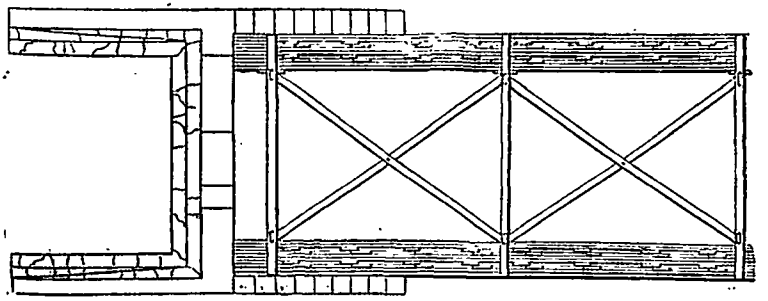


Fig. 2289. PLAN OF RICHMOND BRIDGE.

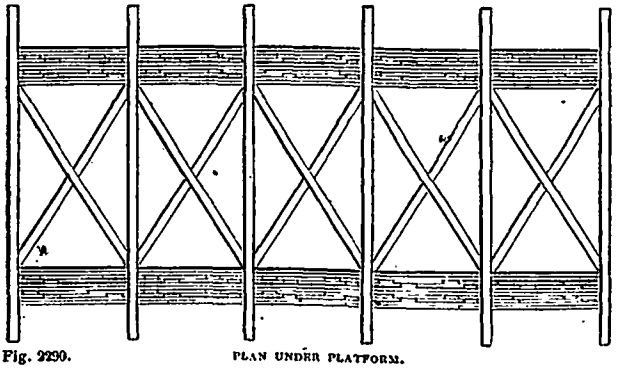


Fig. 2290. PLAN UNDER PLATFORM.

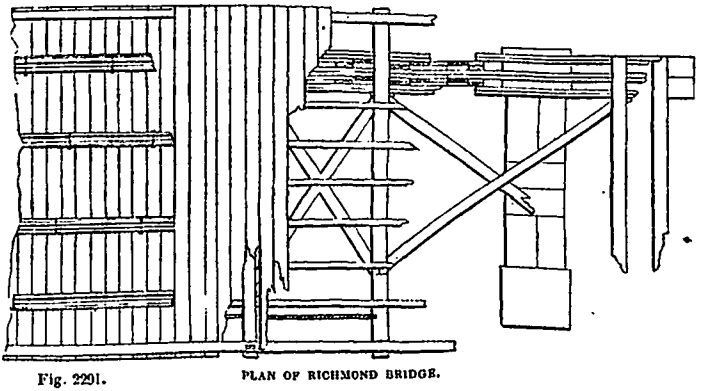


Fig. 2291. PLAN OF RICHMOND BRIDGE.

Bridge over the Schuylkill, at Fairmount, near Philadelphia, was designed by Louis Wernwag, and destroyed by fire in 1838: it was a beautiful piece of carpentry, composed of a single arch, the span of which was 340 feet, and it had no other support than that of

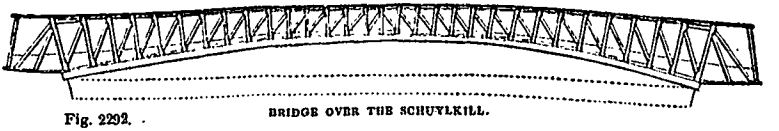


Fig. 2292. BRIDGE OVER THE SCHUYLKILL.

the two abutments; the versed sine was 38 feet, and the breadth of the carriage-way 30 feet. The principal timbers, which were of large dimension, were all sawn down the middle, for the purpose of ascertaining whether they were perfectly sound; and when applied to the bridge they were placed at a sufficient distance apart to allow the tenons of 29 king-posts,

which radiated to the centre, to pass, without any mortises being cut to receive them; by this means the air circulated freely round all the timbers, and dry rot was prevented: the main ribs consisted of three double rows of timbers, laid three deep, or one above the other, the whole bound together strongly with wrought-iron. Between the tops of the king-posts straining beams were introduced, which kept the heads from approaching each other, and in addition two other timbers, placed diagonally, like St. Andrew's cross, were inserted in each of the divisions, strutting the king-posts more firmly and preventing the arch from springing. The abutments, against which the timber arch pressed, were of solid masonry, and carried up considerably higher than the top of the arch. The floor of the bridge was upon girders, laid upon shoulders formed in the sides of the king-posts, to which they were firmly bolted: on the tops of the kings, and in the direction of the transverse girders, were the tie-beams of the roof; these latter not only served to maintain the roof securely, but also the heads of the kings in their perpendicular and proper position. The roof was lightly formed, and the sides of the bridge were close boarded, so that the timbers, or the principles of their construction, could not be seen.

Bridge across the Tees, with an arch of 150 feet span, and a versed sine of 16 feet, is a bold piece of construction: the arch is formed by an upper and lower circular rib, with vertical or rather radiating timbers between them; and the bracing or St. Andrew's cross, inserted between each pair, gives at first the character of 28 hollow voussoirs: each circular rib is formed of two thicknesses of timber 12 inches by 6, bolted together with $\frac{7}{8}$ round bolts, and the heading joints are broken every 10 feet in length; vertical timbers are placed upon these ribs, 12 inches by 10, which support the longitudinal pieces that carry the road: these are also of a similar scantling to the main ribs, and are halved and bolted to the transverse bearers upon which the roadway is formed, which has a clear width of 18 feet.

The abutments at each side are of red sandstone quarried out of the bed of the river, and laid in courses with a face tooled, and a *cast seating* plate separates the stone from the timber arch: the latter was placed by means of a stage formed on piles driven 15 feet apart; and when the two ribs with their radiating timbers and diagonal braces were fixed, the wedges were drawn, and the weight of the ribs thrown upon the iron seating at the abutments, and upon the head joints of the framing, which were protected by two plates of lead, 7 pounds to the foot: after this the piles and stage were removed: in this bridge there was employed 4240 cubic feet of Memel timber, and the total cost was 1200*l*.

Swing Bridges of Iron are now so generally adopted at docks and canals that those of timber are scarcely to be met with: they revolve easily upon a circle, and can be moved with the greatest facility.

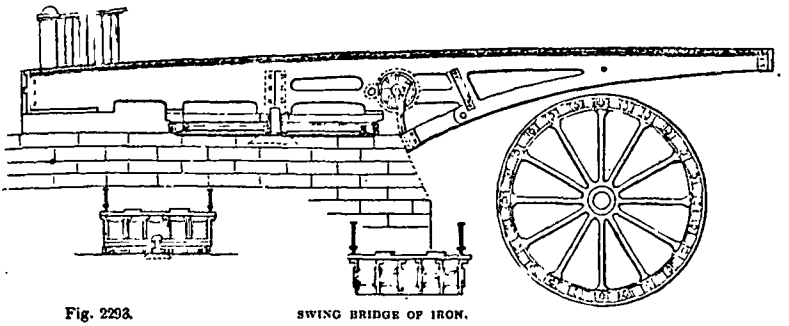


Fig. 2293. SWING BRIDGE OF IRON.

Swing Bridges over canals are simply framed and loaded at the turning end, where an iron circle and wheel facilitate their motion in either direction: where the bridge

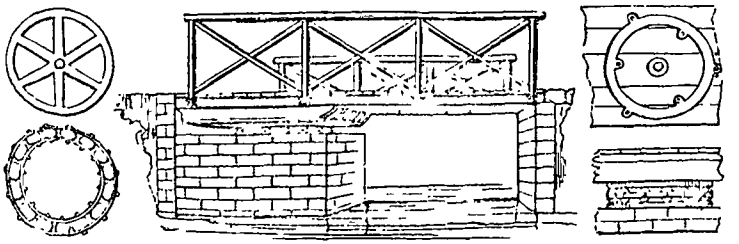


Fig. 2294. SWING BRIDGE.

extends over the abutments to a sufficient distance to counterpoise its weight over the canal a pivot, or small wheel, enables it to be turned readily. Swing bridges may be

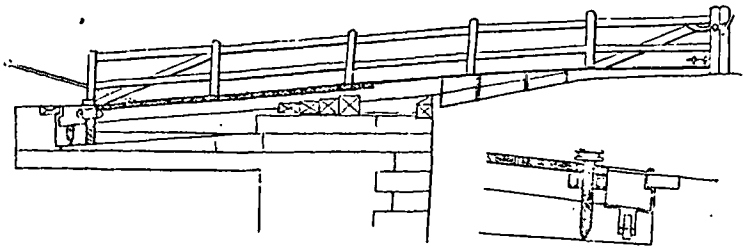


Fig. 2295. UTRECHT SWING BRIDGE.

constructed on the suspension principle, and made to revolve on rollers working in a groove or iron rail: at Havre they are suspended by chains which are fixed

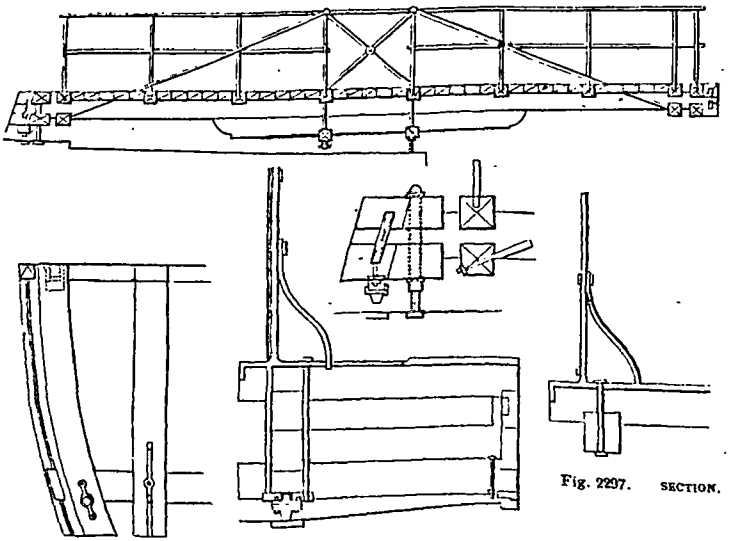


Fig. 2296. SWING BRIDGE.

Fig. 2297. SECTION.

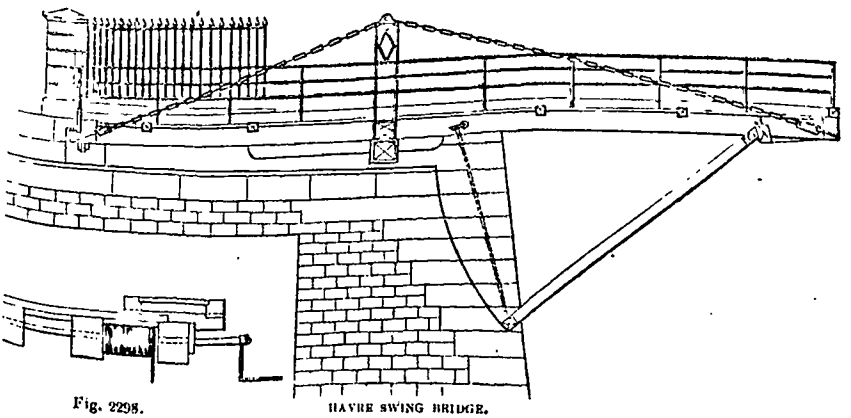


Fig. 2298. HAVRE SWING BRIDGE.

at the two extremities of the principal timbers, and pass over an iron standard, placed over the revolving point; in this arrangement there is considerable strength: at Honfleur the

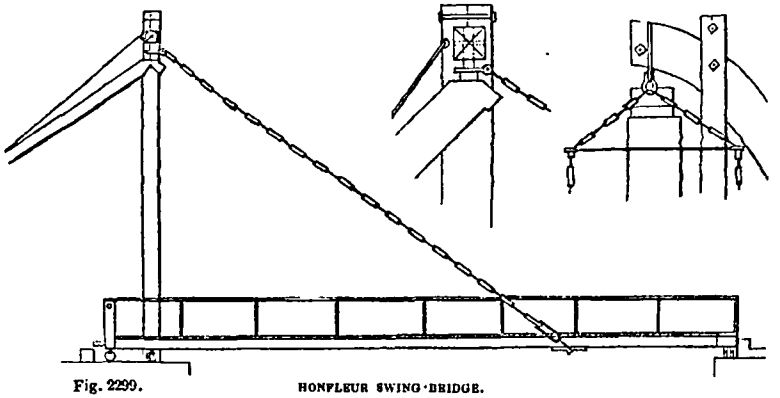


Fig. 2299. HONFLEUR SWING-BRIDGE.

swing bridge is suspended over a lofty standard of timber, round which it revolves: those at Helvoetsluys swing around a pole or iron standard, being counterpoised on the

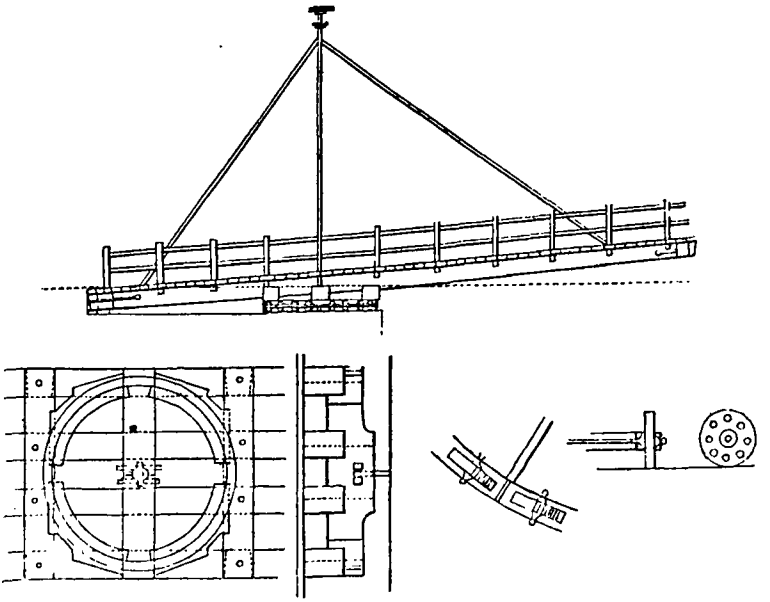


Fig. 2300. HELVOETSLUYS SWING BRIDGE.

banks sufficiently to prevent any inclination from taking place when the bridge is in motion. Double turning bridges may be made upon either of the principles already described.

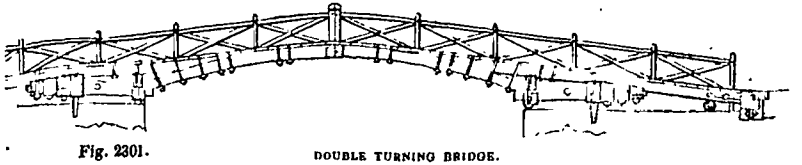


Fig. 2301. DOUBLE TURNING BRIDGE.

Drawbridges are another description of shifting bridges, and consist of a wooden platform, wide enough to allow of the passage of horses and wheel carriages, and extending in length from one side of the watercourse to the other, or from a jetty to a projecting pier on the opposite side: whenever such bridges are adopted, the passage of the water is contracted as much as possible, and only sufficient room left for vessels to pass through; by this means, the platform is rendered as small and light as possible, without sacrificing the necessary strength: it is secured by pivots or large hinges at one of its ends to the jetty, so that it can be raised from its horizontal to a vertical position, which is easily effected by chains attached to each of the corners of the side that is unhinged, and afterwards passed over pulleys, or hung to the ends of long levers, balanced on the top of stout posts, fixed firmly, and braced in that position. Those formerly existing at Brussels were balanced by weights attached to chains passing over standards that stood immediately over the walls of the canals: they were strongly braced, and firmly kept in their vertical position

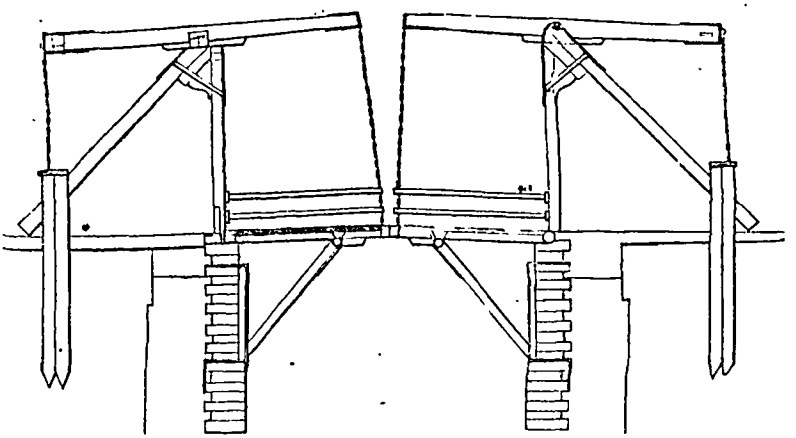


Fig. 2302. DRAWBRIDGE, BRUSSELS.

by means of iron ties. That contrived by Perronet opened in the middle, to allow the masts to pass through; by a windlass mounted in a frame it was easily manœuvred, and raised or let down promptly.

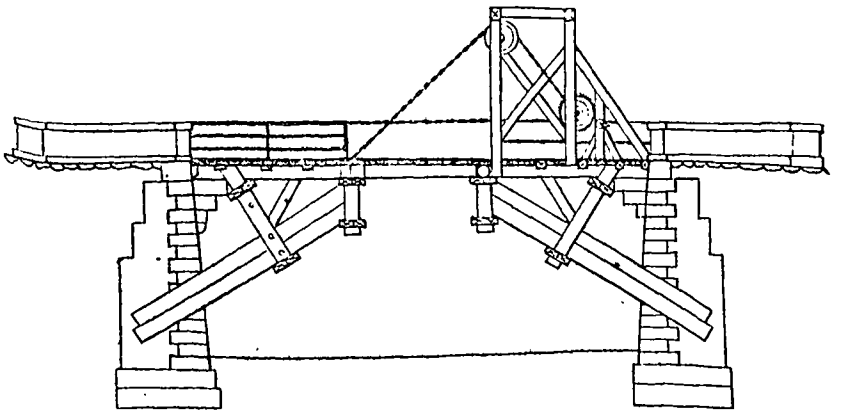


Fig. 2303. PERRONET'S DRAWBRIDGE, BRUSSELS.

Balancing Bridges at Brussels, to work in a quadrant of iron: when in a position to permit a passage over them, they are supported by struts, which have a bearing on a set-off in the masonry; when tilted up, they are maintained in that position by a rack and pinion; at Neuf Brisack the bridge is lifted by a weight over a pulley.

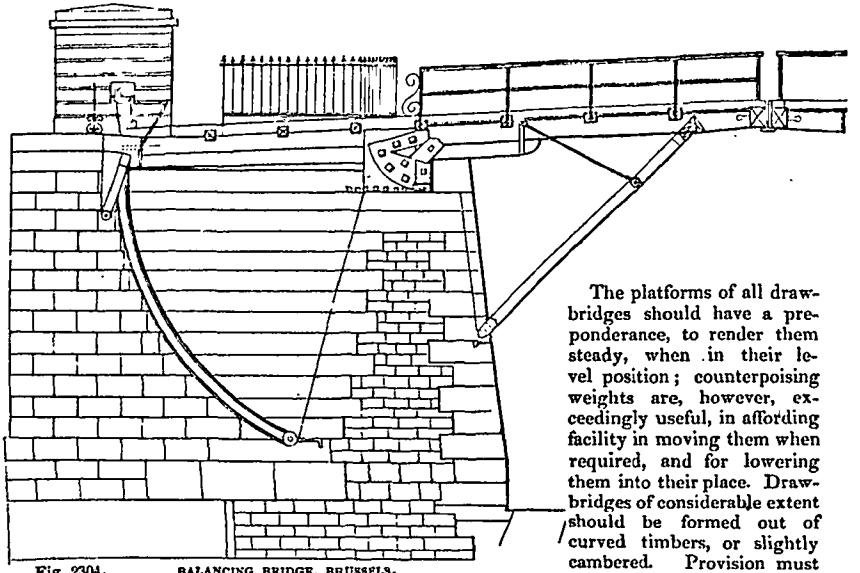


Fig. 2304. BALANCING BRIDGE, BRUSSELS.

The platforms of all drawbridges should have a preponderance, to render them steady, when in their level position; counterpoising weights are, however, exceedingly useful, in affording facility in moving them when required, and for lowering them into their place. Drawbridges of considerable extent should be formed out of curved timbers, or slightly cambered. Provision must be made for the load to which such bridges may be subject, from the possibility of their being crowded with human beings, such a load amounting to one hundredweight at least for every superficial foot, independent of the weight of the materials with which the bridge is constructed: if therefore it be calculated for three times that weight, there will not be more than the requisite strength; and the levers, chains, and pivots must be proportioned to the duties they have to perform.

Where drawbridges were used to cross a ditch or moat around a fortified house or castle, they were hung so that when drawn up they covered the face of the portcullis, and constituted a double protection: the under side of the platform should be cased with iron, or rendered secure against the attempts of the enemy either suddenly to burn or cut it away. The weight of the bridge thus increased requires greater power to hoist it than was ordinarily obtained by the levers and chains manœuvred by the soldiers stationed within the gate-house;

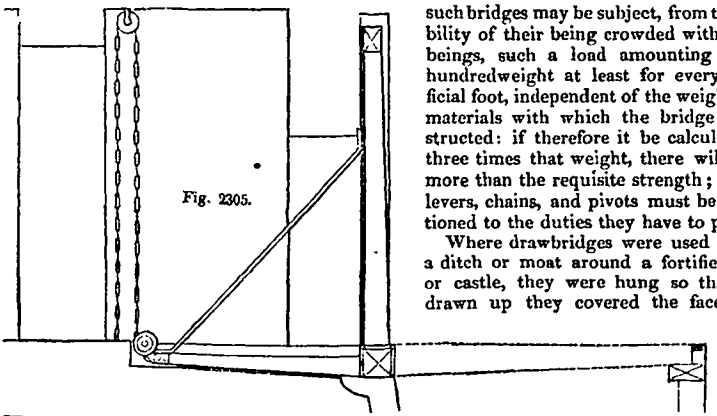


Fig. 2305.

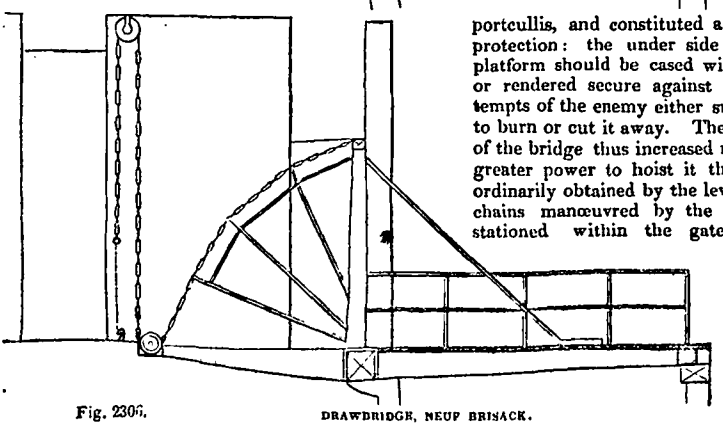


Fig. 2306. DRAWBRIDGE, NEUF BRISACK.

several of the loopholes through which these levers passed may yet be traced round the ruins of our castles.

Rolling Bridges are sometimes substituted for those which swing, the pulleys and wheels being so contrived that a considerable length may be operated upon without danger.

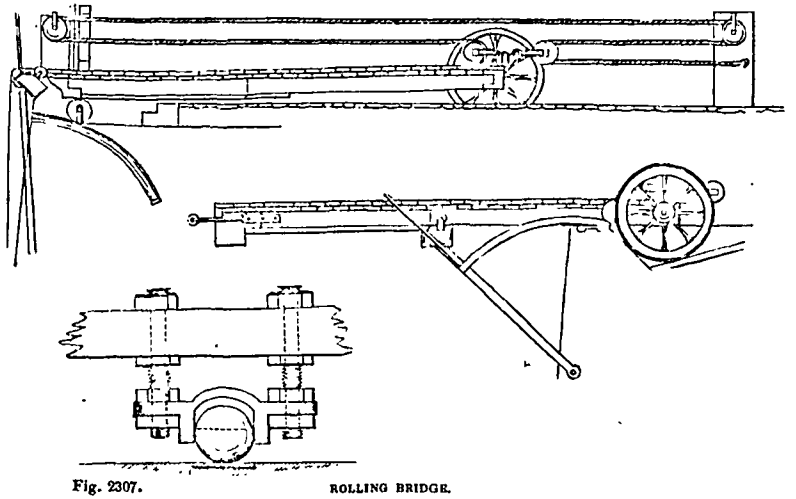


Fig. 2307. ROLLING BRIDGE.

Drawbridge, with a platform composed of three principal timbers, is made to rise by pulling up a lever on each side, which has a pivot that works against the under side of each bearer: when it is required to be let down and form a defence, the frame in which the platform turns upon its pivots is first drawn up by chains; the platform is then swung round, and hangs upright upon the pivots, the longest end descending into the ditch. The dotted circle indicates the various positions of the platform.

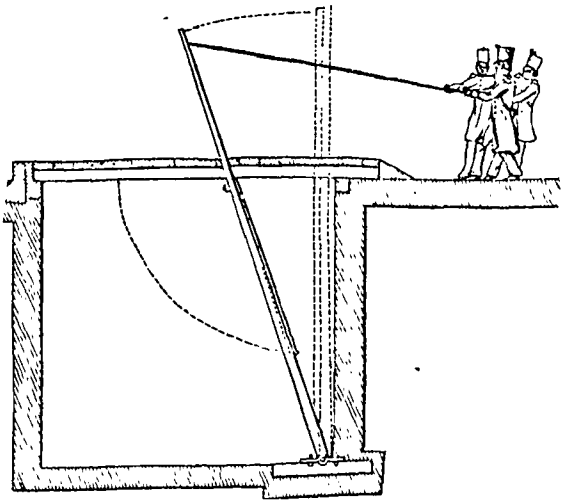


Fig. 2308.

The bridge called *pons subductarius* was hung at one end by a hinge, whilst the other was elevated by some such simple contrivance as the balance or *plyers*; when raised or elevated, it prevented the passage of any one across the ditch or moat it crossed. In many parts of the continent the bridges are still made to draw backwards and forwards, so as to prevent or afford a passage across the water, whenever it is desired. The flying-bridge, or *pons ductarius*, was generally formed in a different manner, leather boats, casks, or metal pontoons, being laid on the river and covered with a platform of timber: they are sometimes made by attaching or hanging several platforms to boats, then dropping them one to the other, the boats being previously anchored or moored in the middle of the river: flying-bridges are occasionally made by laying one platform over another, in such a manner that they can be pushed forwards upon wheels or rollers.

Another Draw-bridge, by which the platform may be first raised from its level and afterwards turned up in a perpendicular direction, consists of two simple levers united by a cylindrical shaft at the lowest end, moving on a pivot or hinge below, and above is another, which lifts up the platform from the recess into which it is laid when the bridge is level; when so lifted it is drawn back, as shown by the dotted lines, and turning on the upper pivot assumes an upright position, dropping into the ditch, where it is lodged in a recess of the masonry prepared to receive it.

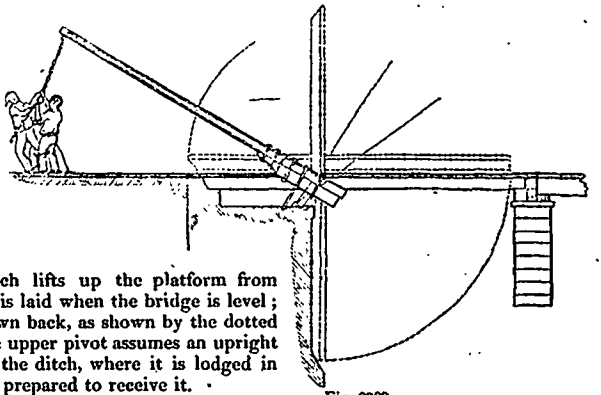


Fig. 2309.

Spherical Rollers for bridges of this description unite many advantages over the pivots, as they produce less friction and can be more easily turned.

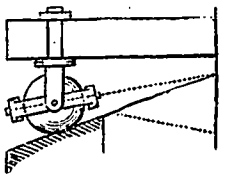


Fig. 2310.

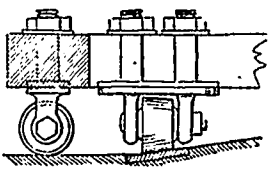


Fig. 2311.

Rope Bridges are of very simple construction: upon a number of cords stretched across a ravine or river may be placed a timber tripod framed together in a triangular shape, upon which timber bearers may be laid, to sustain the planks that are to constitute the road-way: the weight to be transported must guide the engineer in the number and strength of the ropes employed, which are to be secured by piles driven firmly on each bank.

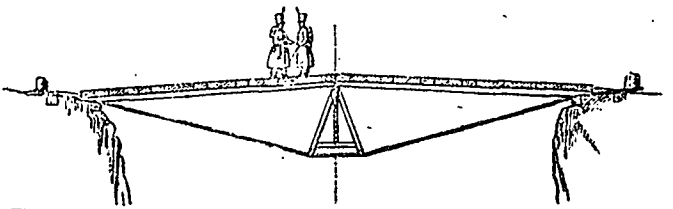


Fig. 2312. ROPE BRIDGES.

Or a Mast may be used to sustain the ropes, when the breadth of the river is too great to admit of the ropes being carried over in one length; the height must be governed by the width of the stream. After ropes are secured to the shores and mast, others are suspended

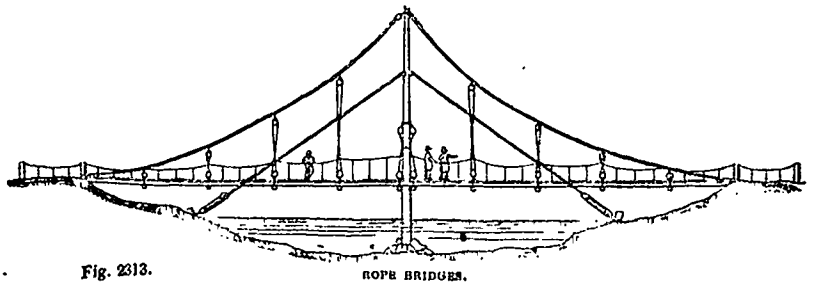


Fig. 2313. ROPE BRIDGES.

by blocks and pulleys to carry the timber platform: such an arrangement in all probability gave the idea of the several wire suspension bridges that have been constructed: for rivers

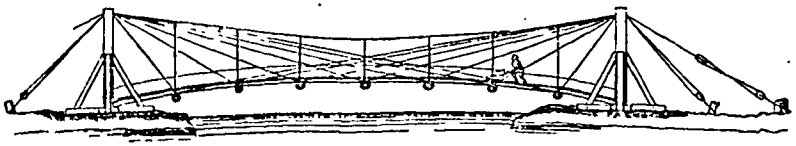


Fig 2314. ROPE BRIDGE.

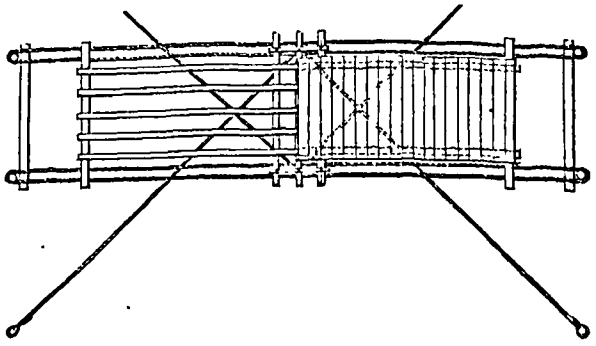


Fig. 2315. PLATFORM OF A ROPE BRIDGE.

of considerable breadth, it is often necessary to erect a framing of carpentry on each shore, to which the several ropes which are to carry the platform are suspended.

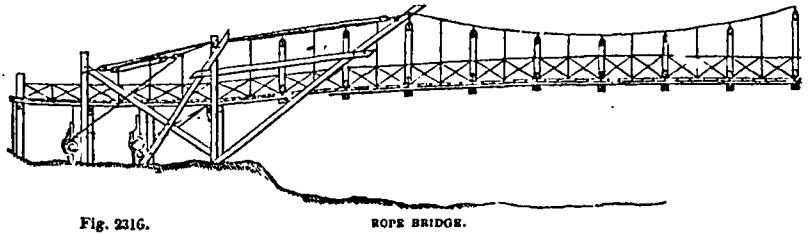


Fig. 2316. ROPE BRIDGE.

Bridges of Boats were of very general use during the middle ages, and are still found convenient over the Rhine, and in many parts of Germany: one at Strasbourg yet remains, upwards of 1300 feet in length, and another at Cologne: they are frequently described by ancient authors, and we have already alluded to them. That over the Seine at Rouen was constructed in 1700 by an Augustine monk, named Nicolas: various forms are given to the boats, which are flat-bottomed, and placed at a distance from centre to centre, equal to their length, or a trifle more; they are loaded with stone or ballast, so as to enable them always to remain at the same height above the water, and are secured together by the longitudinal timbers that pass over them, or by chains that cross diagonally from one to the other.

Anchors dropped in the stream, to which the boats are moored, enable them to maintain their position, and, when it is required to make an opening to let the vessels pass, two of the boats with the platform upon them are floated on one side, and held in their new position by anchors laid down for the purpose. The bearers on which the platform is laid may be formed of three or more longitudinal timbers, over which are short joists to receive the planking, or by at once laying the planks transversely on a greater number of long timbers; the nature of the stream and the strength requisite for the bridge must determine which method is preferable.

Floating Bridge across the Hamoaze, between Torpoint and Devonport, consists of a flat-bottomed vessel, 65 feet in length, and in width at midships 45 feet; it is further lengthened by a drawbridge at each end, where its width is only 38 feet 6 inches: when freighted, its draught of water is 30 inches, and the clear depth of the hold is 4 feet 3 inches; it has its sides curved vertically, in order that the spray may not so readily mount, and to prevent

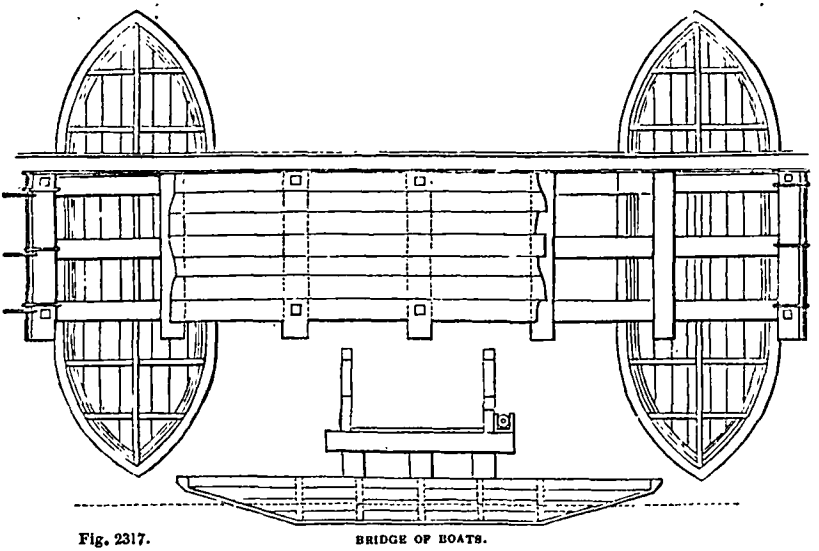


Fig. 2317. BRIDGE OF BOATS.

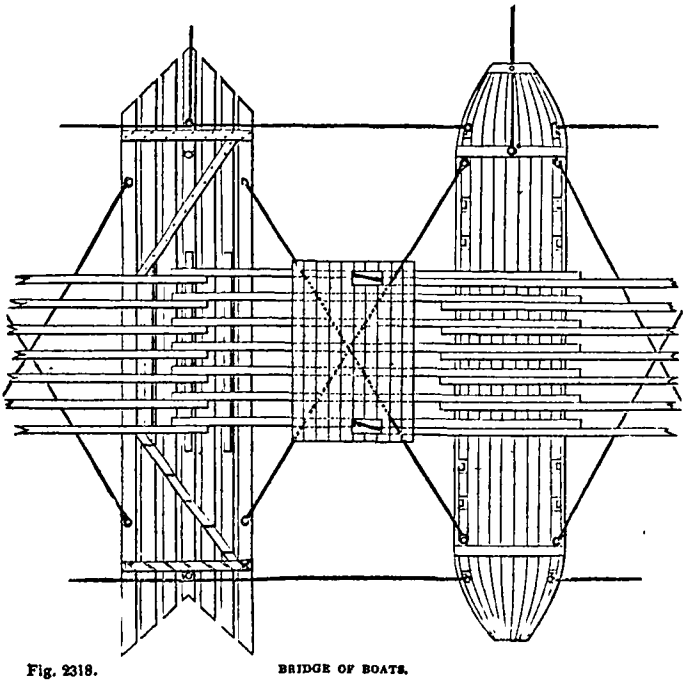


Fig. 2318. BRIDGE OF BOATS.

the effect of the waves breaking over. The roadway is cross-battened, to prevent the cattle from slipping, and the sides are fenced in: the drawbridges are suspended by two three-quarter-inch chains, one of which forms a guard-rail, and the other passes through the engine-house, where it is connected with a small purchase machine. This bridge at the time of low-water is passed in 7 minutes, and at high-water in 8, at a spot where the Hamoaze is 2550 feet wide at high-water, and 2110 at low, the greatest depth being 96 feet, and at low-water 18. The current at the ordinary spring-tides runs from 260 feet per

minute to 330, which is considerably increased when the wind is north-west and there are heavy land floods. Two chains which pass through the bridge over two cast-iron wheels are laid across the river, and fastened at the opposite banks; they are of inch-iron, and each link is made to a gauge to fit the wheels and prevent its slipping off: the chains sink to the bed of the river when the bridge is alongside either shore, and as it is put in motion, they form arcs of a circle, the ends on shore, to which weights are attached, rising and falling from 5 to 8 feet in the shafts made to receive them.

Two steam-engines, each with a cylinder of 19 inches diameter, and 2 feet 6 inches stroke, working at a pressure of 3¼ pounds per inch, and at an average speed of 95 strokes per minute, is the moving power; these turn a shaft, at each end of which is a large cast-iron wheel, whereon the guide chains rest. To prevent the chains which cross the Hamoaze from becoming tight and impeding the navigation, their ends have heavy weights attached to them, in shafts 25 feet deep and 16 feet square, at the head of each landing-place, the weights being of cast-iron, each loaded with 5 tons; these enter the shafts over cast-iron sheaves, 2 feet in diameter, so that when there is a strain upon the chains the weights rise and fall. The feeding water, which supplies the one boiler common to the two engines, is obtained on the eastern shore, and the waste steam is made to pass into the tank, where it assists in raising the temperature of the water contained in it.

Centres.—The systems laid down for the construction of roofs, particularly those having a convex form, as domes and cupolas, apply also to that of centres: a pair of principals may equally serve for the construction of an ordinary roof, as for the formation of a centre, care being taken to give it strength in the parts where the greatest weight is deposited; this strength varies according to the nature of the material to be supported: brick, rubble, and freestone, differing in weight, require different degrees of support.

Timber Centres, formed of a series of principals or trusses, are always adopted when the arches are of freestone and strength is required; in constructing the arches of a bridge of any considerable diameter, where the form is that of a semicircle, or semi-ellipsis, after the voussoirs are laid to a certain height, the timbers of the centre are compressed, occasioning the crown or upper portion, which is not loaded, to spring, producing a considerable change of form; this inconvenience is only to be obviated by loading the summit as the process of laying the voussoirs advances; but this precaution will not prevent the centre from altering towards the haunches: whenever a tie-beam is omitted in that part where the greatest pressure occurs, compression and change of form are the consequence. Centres with tie-beams are always to be preferred to those formed by parts of polygons inscribed within each other; when constructed without horizontal timbers, in the direction of the greatest compression, they must yield very considerably, occasioning great derangement and inconvenience: various principles have been acted upon in later times for setting out centres, and for the disposal of the principal timbers.

M. Lorgna, of Verona, in a work entitled *Saggi di Statica e Mecanica applicate alle Arti*, gives the diagram here introduced: but the timbers C, D are too much inclined, as are those at E, G, to have the requisite effect; the pendant timbers A Z, B T, are not well placed, and the small struts *h*, *i*, are not calculated to discharge the several weights F, A, B, I, resting on the centre, which are expressed by the balls *a*, *b*, *c*, *d*.

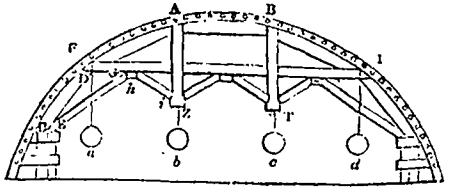


Fig. 2319.

The art of disposing various lengths of timber, so as to form a perfect centre, capable, without undergoing any change in its form, of carrying the weights of the voussoir throughout, until the key-stone which locks the whole is placed, and to determine the scantling for the various pieces composing it, requires greater knowledge than is usually possessed by the ordinary builder. Rondelet observes that mathematicians, who have written largely on the subject, have not entered sufficiently into detail to make their labours practically useful; their theory is so general that it cannot be applied to particular cases; and when it is considered that their formula does not embrace every quality that the materials may possess, or comprise the kind of workmanship adopted in putting the pieces together, it is not surprising that the results are so much removed from truth, and that there should be such material differences between those who practise the art of construction.

After examining with the greatest attention all that Pitot, Couplet, Freziers, and Lorgna of Verona had written, Rondelet found that their theories simply proved, that all the pieces of timber composing a centre ought to be so combined as to support in the most advantageous manner possible all the stones or voussoirs, which were supposed to slide in their joints, more or less, according to their inclination: as the surfaces of stones

are not sufficiently smooth to slide, unless the plane on which they are placed ceases to be horizontal, experiments have been made to ascertain at what inclination they can support themselves; and it has been found that hard stone, which slides most easily, does not begin to do so until inclined about 30°. The same experiments made with stone bedded in fresh mortar give for hard stone from 34° to 36°, and for soft, which by absorbing the moisture of the mortar forms itself into a body almost immediately, up to 45°, when the centre of gravity of the stone does not fall out of its base. Thus by taking 30° for the point where the voussoirs begin to slide, we are sure of results above those which experience would give; whence it would appear that the centre ought only to begin at that height. In several constructions of ancient bridges, such as the Pont du Garde and Ponte Sisto at Rome, we still see the projecting stones on which the bases of the centres were placed; they are from 25° to 28° above the springing; nevertheless for centres of vaults of great diameter, the tie-beam of which is required to be supported at a certain distance, it is better to begin the centre at the springing, so as to strengthen the tie-beam underneath. The weight on the centres is not material until above 30°; it then goes on augmenting with the voussoirs, until the key is placed which supports the vault and relieves the centre of its weight.

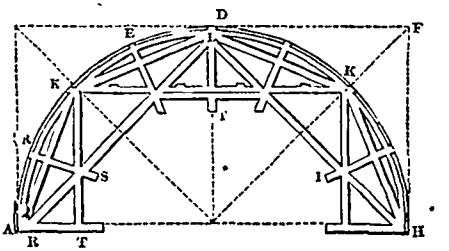


Fig. 2320.

In order to find a combination of pieces of timber which shall resist the efforts of the voussoirs, we must first determine the position of the tie-beam. For this purpose, whatever may be the centre of the arch, whether lofty, a semicircle, or an ellipsis, draw from the points A and D, figs. 2320, 2321, 2322, 2323., two indefinite tangents which meet at the point F, through which draw a perpendicular to the curve; the point K, where it intersects, will determine the position of the tie-beam: having then divided the part K D into two or three parts, in proportion to its developed length, draw through the points of division E and G other perpendiculars to the curve, which will indicate the position of two intermediate king-posts. From the point I, where the direction of the first will meet the tie-beam, draw the line H I L, which

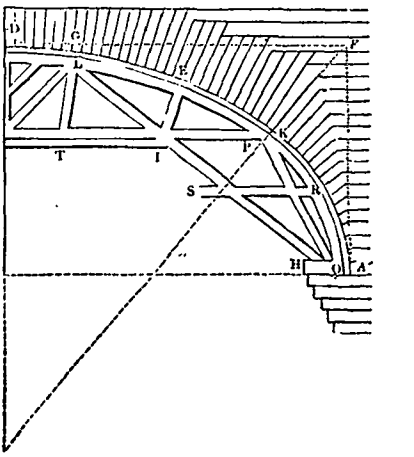


Fig. 2321.

will indicate below the position of an inclined piece to support the bearing of the tie-beam, and above, that of a brace to sustain the top of the king-post L T, supported on the other side by the brace L H, which abuts against the king-post of the centre. The part below the tie-beam will be divided into two, three, or four parts in proportion to its length, through which must be passed the binding pieces R, S, to support the inclined pieces, posts and braces which unite these, as well as to prevent their yielding in the direction of their length.

The scantlings of the various timbers must be found in the manner before indicated, taking care to observe which are pressed in the direction of their ends, and which in their width, and it is important to consider that it is not only requisite that each of these pieces should have

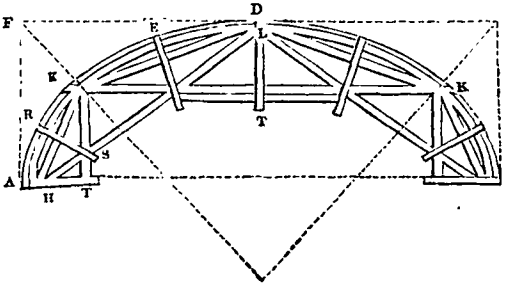


Fig. 2322.

strength sufficient to resist a portion of the weight which is applied to it, but also to resist any effect arising from partial movement, or from imperfections in the timber or in the workmanship of their framing. Timbers, which have great weights to support, and which are pressed in the direction of their length, should be as many inches square as they are long in feet, or from a twelfth to a tenth of their thickness in length: when drawn in the direction of their length, from a thirtieth to a twenty-fourth: and bearers, loaded at right angles, or perpendicular to their length, from a twenty-fourth to an eighteenth.

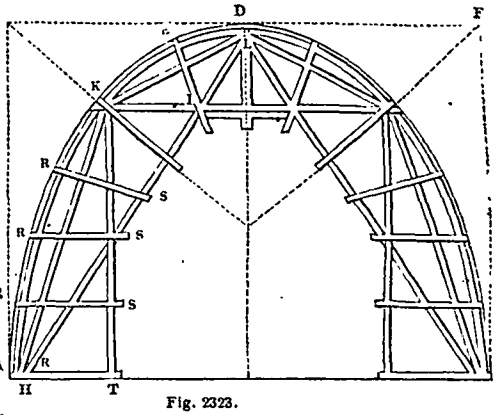


Fig. 2323.

A centre for a semicircular arch with a tie-beam may be determined according to the rules before given: for an ellipsis the same rule is applicable: for an elongated ellipsis, the timbers may be similarly arranged.

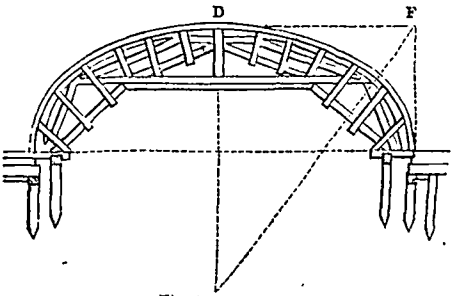


Fig. 2324.

In examining the stiffness of centres, the chief point for our consideration is, where do the arch-stones first begin to press upon them, and what is the pressure exerted by the several voussoirs? We have seen that stone placed upon an inclined plane does not begin to slide, unless it slope a little more than 30° from the horizontal plane; consequently any stone which did not slide upon its bed would not bear at all upon the centre. Hard stone laid in mortar slides when the angle is beyond 34°, and one of a soft nature will remain firm when the angle which its joint makes is as much as 45°; this point has been termed the angle of repose, and if we suppose the pressure to be represented by the radius, the tangent of the angle will represent the friction; hence if we call the pressure unity, the friction will be 0·625, or according to Perronet 0·8. The next course of voussoirs after the angle of repose will press upon the centre, as will every succeeding course, with an increased weight. The relation between the weight of a voussoir and its pressure upon the centre in a direction perpendicular to the curve of the centre may be determined by the following equation, W (sin. $a - f \cos. a) = P$; where W is the weight of the arch-stone, P the pressure upon the centre, f the friction, and a the angle which the plane of the lower joint of the arch-stone makes with the horizon.

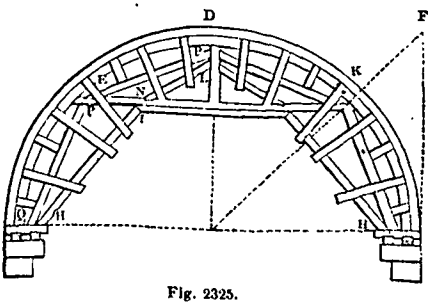


Fig. 2325.

When the angle which the joint makes with the horizon is —

34°	P = ·04 W		48°	P = ·33 W	
36	P = ·08 W		50	P = ·37 W	
38	P = ·12 W		52	P = ·40 W	
40	P = ·17 W		54	P = ·44 W	
42	P = ·21 W		56	P = ·48 W	
44	P = ·25 W		58	P = ·52 W	
46	P = ·29 W		60	P = ·54 W	

When the plane of the joint becomes so much inclined that a vertical line passing through the centre of gravity of the voussoir does not fall within the lower bed of the stone, the whole weight of the voussoir may be said to rest upon the centre. If it be required to determine the weight of any voussoir, we must take from the table the decimals opposite the degrees at which it is laid; for example, to obtain the pressure upon the centre of the twenty degrees which commence at the joint: making an angle of 32° with the horizon, or from 32° to 52°, we must add them together, and multiply this sum by the weight of that portion of the voussoirs comprehended between 2°, and the product will be the pressure of 20° of the arch upon the centre. Supposing the frames of the centre to be 5 feet apart from the middle of each, the depth of the voussoirs 4 feet, and the space comprehended between 2° of the arch, measured at the middle of the depth of the stone, 1·5 feet, the solid content of which is 30 cube feet, the weight of 1 foot being 150 pounds; the weight of 2° will be $30 \times 150 = 4500$ pounds: adding the decimals together from 32° to 52°, the sum is 2·26, which multiplied by 4500, gives 10·170 pounds for the pressure of 20 degrees.

The two middle arches of the *Bridge of Cher, near Tours*, one 62 feet, the other 59 feet, has centres formed upon this construction.

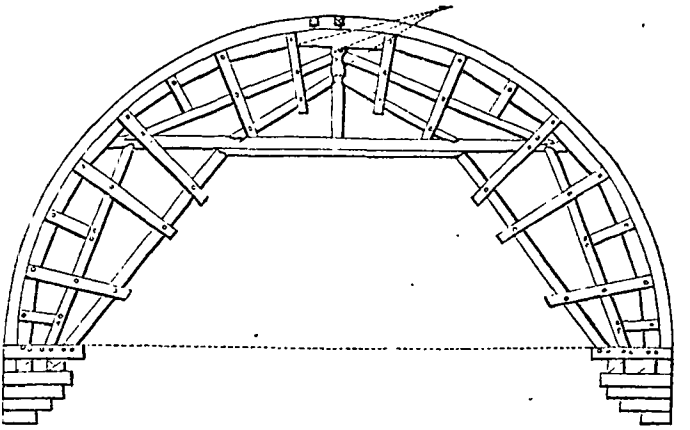


Fig. 2326. BRIDGE OF CHER.

At the Bridge of the Assise, near Tours, where the arches had 64 feet span, and the thickness of the arch was 3 feet 2 inches, this sort of centre was also used: the stone employed was of the ordinary weight, and the principals which formed the centering were placed 6 feet apart.

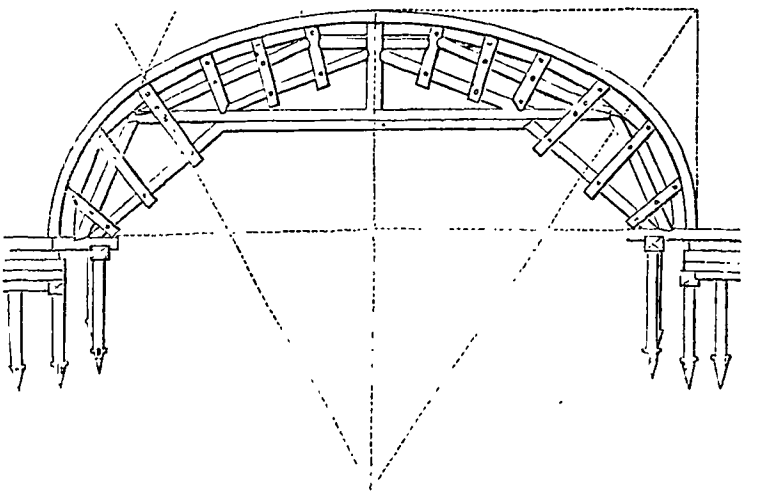


Fig. 2327. BRIDGE OF L'ASSISE, NEAR TOURS.

Perronet's system of forming Centres was to omit the tie-beam, and from his elegant work on bridge-building a few examples are selected: this engineer imagined that when the

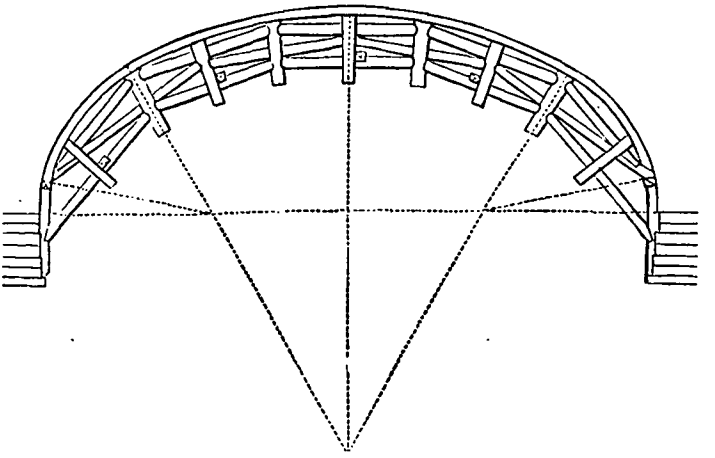


Fig. 2328. CENTRE, 76 FEET SPAN.

timbers were prolonged they found a portion of their support in the opposite sides of the arch; a centre so contrived may be regarded as composed of a number of trusses or framed voussoirs, and are subject, as he found, to great disarrangement, if not loaded very carefully.

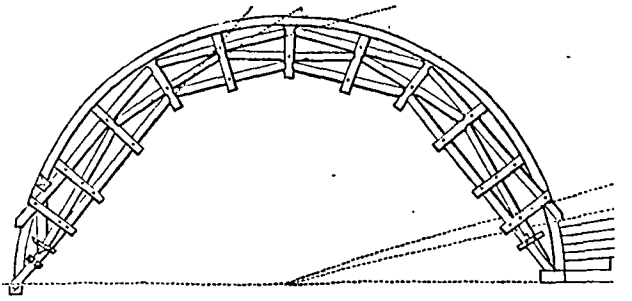


Fig. 2329. CENTRE, 64 FEET SPAN.

The centres used by Labelye for the construction of the arches of Westminster Bridge were an improvement upon those of Perronet, and calculated to bear more equally the weight that was placed upon them, see fig. 429. p. 424. The centres for Blackfriars Bridge were contrived partly upon Labelye's and partly upon Perronet's principles, but they were supported upon inclined timbers, which greatly assisted the wedging up and gradual lowering of them after the last voussoir was placed; see fig. 432. p. 428.

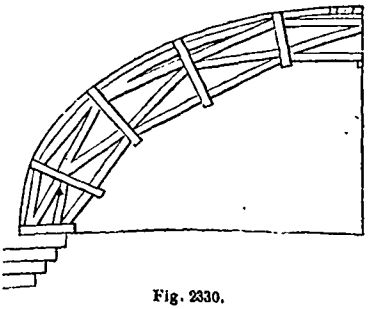


Fig. 2330.

That of Cravant, situated on the River Yonne, had a span of 64 feet and a rise of $\frac{1}{9}$: there were five trusses or sets of principals, placed 5 feet 6 inches from middle to middle; each was composed of three triangles, the larger timbers of which were from 16 to 19 feet in length and 10 inches square; the pendant binding-pieces were nearly 8 feet in length, and of the same scantling. The thickness of the arch at the key was 4 feet 3 inches: the

stone employed in its construction was of the ordinary weight; this centre was found too weak for the purpose.

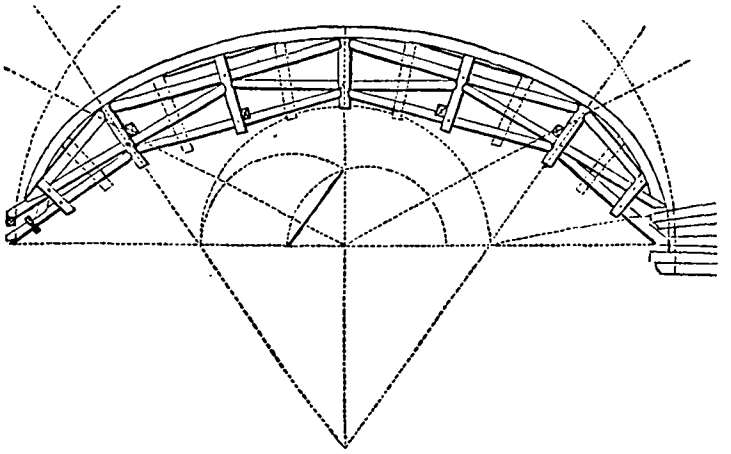


Fig. 2331. CENTRE, 64 FEET SPAN.

The Arches of St. Edme were 95 feet 6 inches span, and rose 27 feet 8 inches: the principals forming the centres were five in number, and placed 7 feet apart. The timbers used in their construction varied from 19 to 24 feet in length, were from 15 to 16 inches square, and sufficiently strong for the purpose; the thickness of the arch at the key was 4 feet 10 inches.

The Centres of the Bridge at Mantes, contrived by Perronet, show the care and attention he bestowed upon this portion of his constructions, and the ability he evinced in forming

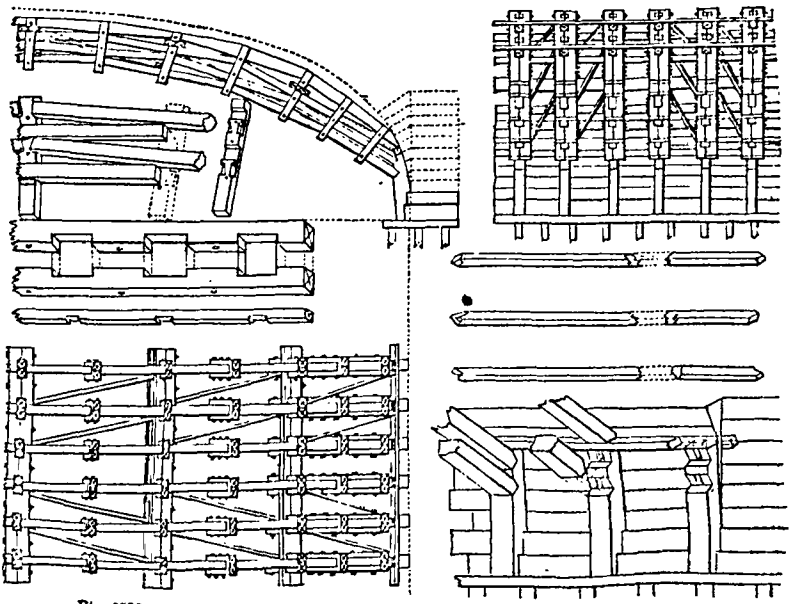


Fig. 2332. BRIDGE AT MANTES.

the temporary bridge and scaffolding for the purpose of hoisting them was equally admirable. The thickness of the arch at the key was 4 feet 4 inches, and it continued

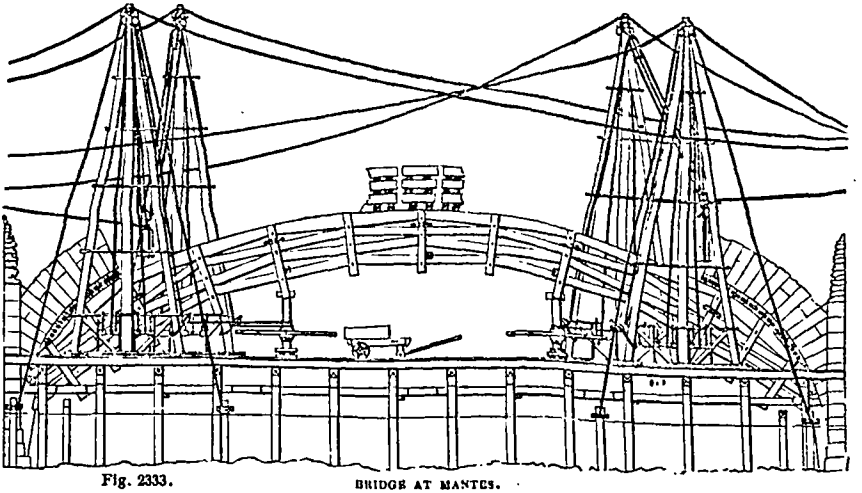


Fig. 2333. BRIDGE AT MANTES.

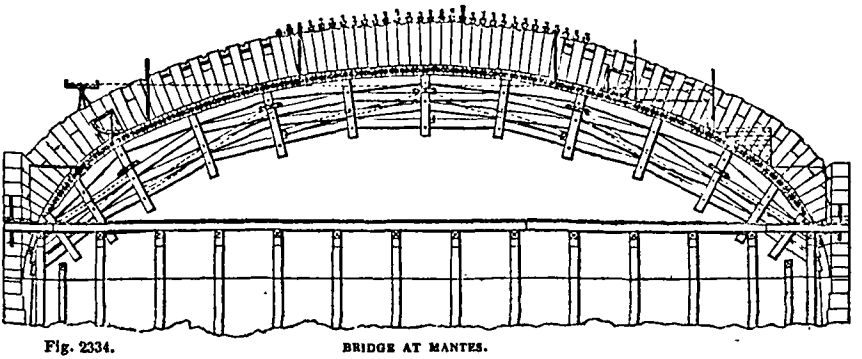


Fig. 2334. BRIDGE AT MANTES.

the same throughout to its abutments; as there were six principals or ribs to each centre, it required considerable power to raise them into their places, which was well accomplished by strong tackle attached to lofty poles.

We have evidence that this system of Perronet's was previously adopted by Hardouin Mansard, when the bridge at Moulins was constructed under his direction, and it would appear at first sight that the timber was placed in a manner to be susceptible of the greatest resistance: but it has not always succeeded well where it has been applied; the multiplicity of timbers occasions too much play about their joints, and centres so formed are very liable to change their figure. The centres of the bridge at Mantes, the ribs of which were 6 feet 6 inches apart, were formed of four courses of rafters or inclined pieces 18 inches square, and their settling was found to be very considerable; when the voussoirs were placed at the haunches, the centres bent under the weight, and rose at the summit, which it was necessary to load considerably, to keep the centres in their true form.

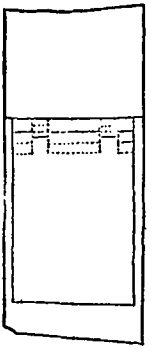


Fig. 2335. CENTRES OF ARCHES.

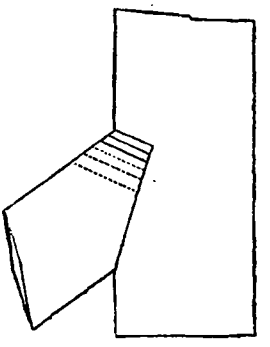


Fig. 2336.

The Centres of the Bridge at Neuilly were similar to those at Mantes, and the span of the arches was equal to that of the great arch of the latter: but this is not so flat, and although the thickness of the arch be less than that at Neuilly, and the principals only 6 feet 6 inches distant from each other, they were found to be too weak: each principal had seven or

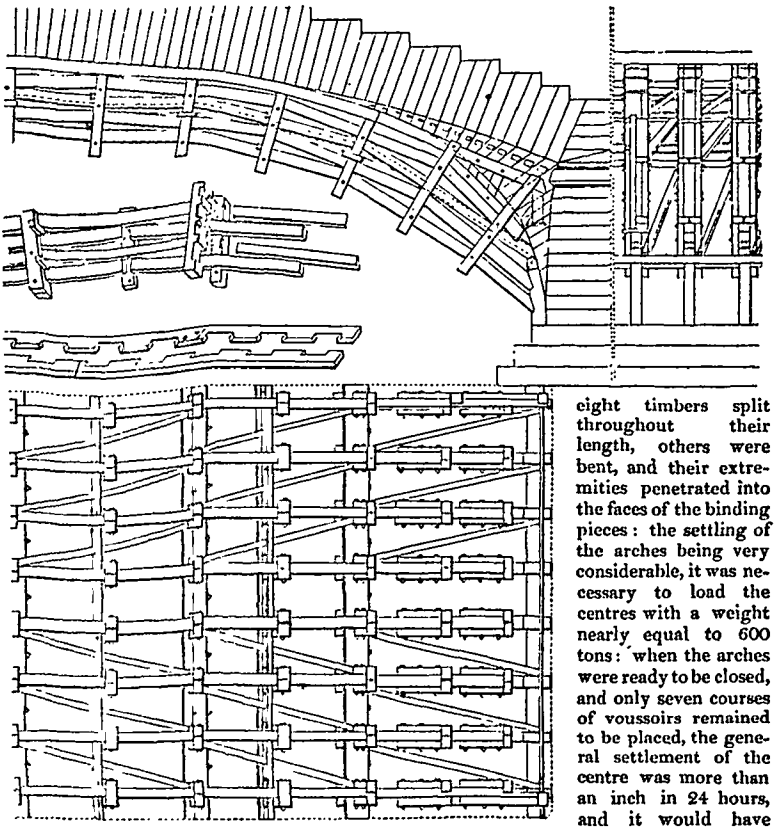


Fig. 2337. BRIDGE OF NEUILLY

eight timbers split throughout their length, others were bent, and their extremities penetrated into the faces of the binding pieces: the settling of the arches being very considerable, it was necessary to load the centres with a weight nearly equal to 600 tons: when the arches were ready to be closed, and only seven courses of voussoirs remained to be placed, the general settlement of the centre was more than an inch in 24 hours, and it would have been still greater, but for the celerity with which the work was carried on, and the precaution taken to strengthen it by braces extending from one principal timber to the other, and by placing struts between the courses of the opposite voussoirs. The openings in the framing were caused by the timbers not bearing equally against the binding-pieces throughout the whole surface of their extremities, and an attempt was made to correct this defect by cutting each extremity in the form of an arc of a circle: this disposition, which was adopted at the bridges of St. Maxence and of Concord at Paris, was successful in preventing the inclined timbers from splitting, but they continued to penetrate into the binding-pieces; it also increased the play of the framework, and rendered the centres more susceptible

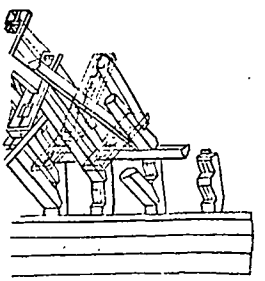


Fig. 2338. BRIDGE OF NEUILLY.

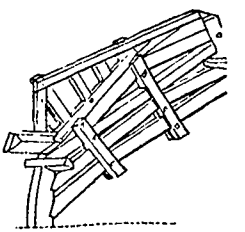


Fig. 2339.

of changing their form. The ends of the two inclined timbers in the upper part might be framed with bevelled shoulders, thus making them bear upon each other; the binding-pieces would continue to embrace them, and the whole being consolidated by bolts would be more firm.

In forming the centre of a bridge, the weight should be equally borne throughout, and the parts should be made sufficiently strong to support any portion or the whole of the pressure to which it is submitted; wherever the timbers abut end to end, a socket of iron should be used, as was done in the centre of Waterloo Bridge, London. The timbers should intersect one another as little as possible, and should never be halved or cut into, as either practice causes a great loss of strength.

The Centres used at the Bridge of Orleans were not sufficiently strong as originally projected, and some braces were added to it in the course of the construction, extending from one principal to another. The scantling of the timbers was about 15 inches square,

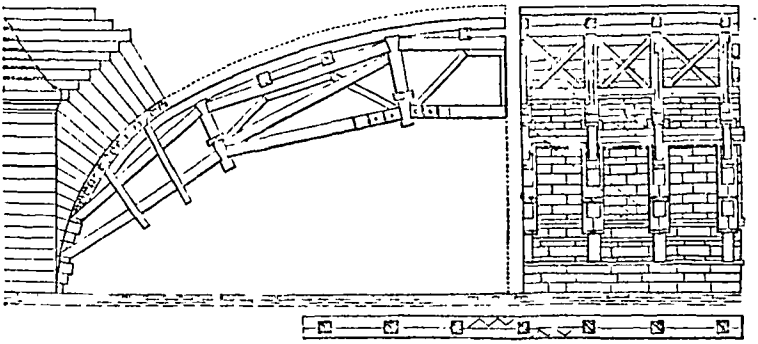


Fig. 2340. CENTRES OF BRIDGE OF ORLEANS.

that of the braces 9 inches, and that of the needles 16 inches: these centres were successful, and proved of sufficient resistance, although not very much loaded with timber: they were composed of fewer pieces, which rendered them less liable to change form, which a weight of 100 tons was sufficient, when placed on their summit, to prevent.

Fig. 2341. represents the centre used at the bridge of Nemours on the Loing: in an arc so flattened, the whole arch bears equally on the centre, and removing the wedges becomes very difficult: striking the centre was in this instance effected by destroying by degrees the extremities of the second and third rows of inclined timbers, at the point where they framed into the side timbers; the centre, being no longer sustained except by the upper row, sunk a little, after which it was easily taken down. The centres employed in the construction of the bridges of Neuilly and Mantes have but little strength, notwithstanding the quantity of timber employed in them, each course of which may be considered in such centres as an assemblage of several levers, united at their extremities by hinges or turning joints, and loaded with different weights; we know that the equilibrium of such a system depends on certain conditions, which are the same as in the polygon, so that the length of the levers being given, their respective inclination depends on the weights which they support, and are functions determined by those weights: before the centre is loaded by the voussoirs, it is in a state of equilibrium; but it is no longer so when the first voussoirs are laid, and the centre would crush if no attempt were made to establish the equilibrium, by loading the upper parts provisionally; by the advancement of the work, the equilibrium is again broken, and fresh settlements arise, which would become dangerous if the weight on the top were not increased, and the arch completed as quickly as possible: thus at different periods the equilibrium is alternately broken and re-established, and the centre is in a continual movement during the whole time of the construction.

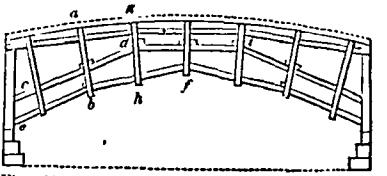


Fig. 2341. CENTRE OF THE BRIDGE AT NEMOURS.

Several engineers have believed that this movement of the centre during the placing of the voussoirs, far from injuring the construction of large arches, serves on the contrary to ensure it. A distinction has been made between fixed and movable centres, and the preference has often been given to the latter; the only reason for this preference must arise from the idea that a movable centre yields to the settlement of the arch, which, with the com-

pression of the joints, begins before the striking of the centre, and even before the arch is closed; by the time the centre is struck, the mortar has already acquired much consistency, and no sensible change can happen in the figure of the arch: but it is very easy to imagine that a centre composed so as to remain fixed during construction should have the same properties; for whatever may be the system of the carpentry of a centre, in gradually destroying the points of support on which it is placed, its resistance may always be insensibly diminished, leaving it the necessary strength for supplying that which the arch has not yet acquired; which resistance should continue until after the joints having been compressed as much as possible, the arch can sustain itself, and is no longer susceptible of any movement. The only precaution to be used is not conducting this operation with too great rapidity.

The question of fixed and movable centres was examined by the engineers of the Ponts et Chaussées in France, on the occasion of the construction of the arch of the bridge of Jena, and they decided in favour of the first; the success attending the execution of these arches confirmed the propriety of this decision. With respect to the system of carpentry to be employed for fixed centres, it appears that, in order to have requisite solidity, they should be composed of three parts at most, the two inferior ones immediately resting on corbels placed at the springings, to carry the upper parts; by such an arrangement there will be no tendency to a change of form, at any epoch of the construction of the arch; for it is evident that the only condition necessary for the equilibrium is, that the number of the voussoirs at the springing should be the same at each side.

Fig. 2342. represents a centre formed after these principles, for the construction of the arches of the bridge of Moulins, which was built on a general radius, on which was established a centre, on points of support taken on the same radius, evidently producing the greatest solidity: the principals were distanced at 7 feet from centre to centre, and maintained by horizontal binding-pieces, and by St. Andrew's crosses; the timbers were 13 inches square.

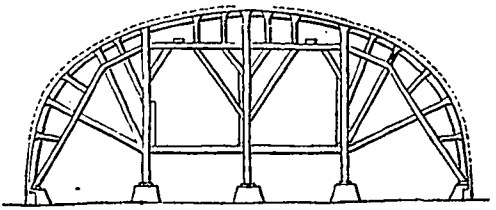


Fig. 2342. CENTRE AT MOULINS.

The centres of Westminster Bridge, constructed by Mr. King, were an improvement upon those designed by Perronet. Two timbers resting on the abutments incline, and meet at the top of the arch, forming a large triangle; this is crossed and braced again in various directions, forming as it were seven large voussoirs: there is considerable strength in such an arrangement, and it combines a portion of the principles afterwards adopted with so much success.

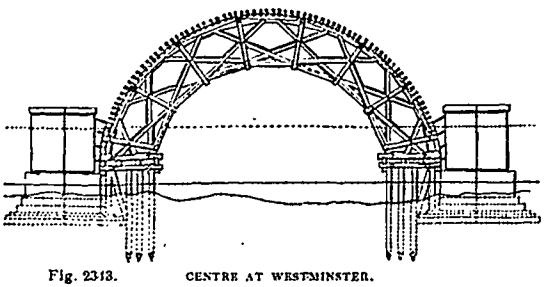


Fig. 2343. CENTRE AT WESTMINSTER.

Centres of 130 feet span have been formed by vertical and horizontal timbers braced by others in a diagonal position: they are exceedingly simple, and are easily put together and taken down: the upper portion is contrived to rest on wedges, and can be lowered without disturbing the rest; and by striking the inclined supports at bottom, their position can be altered when required.

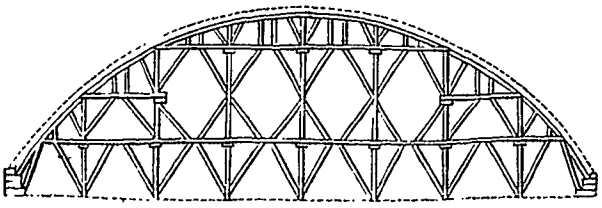


Fig. 2344. CENTRES OF 130 FEET SPAN

The Coldstream Bridge had a frame with a tie and a series of braces united; this truss supported on each side a portion of the centre, or the ribs, on which were laid the planks for turning the arch; this was designed by Mr. Smeaton.

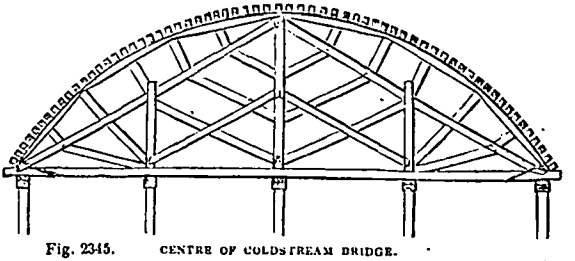


Fig. 2345. CENTRE OF COLDSTREAM BRIDGE.

The Centering used by Mr. Telford at the bridge of Cartland Crags possessed considerable novelty, and was well adapted for its purpose: as the piers were built, care was taken to provide for a lodgment of the inclined timbers which were to support the second platform, on which the centre was to be constructed to carry the whole of the arch above it. The temporary platform on which the materials were brought, previously to lowering to their place, rested upon the centre, and by its weight assisted in steadying the work.

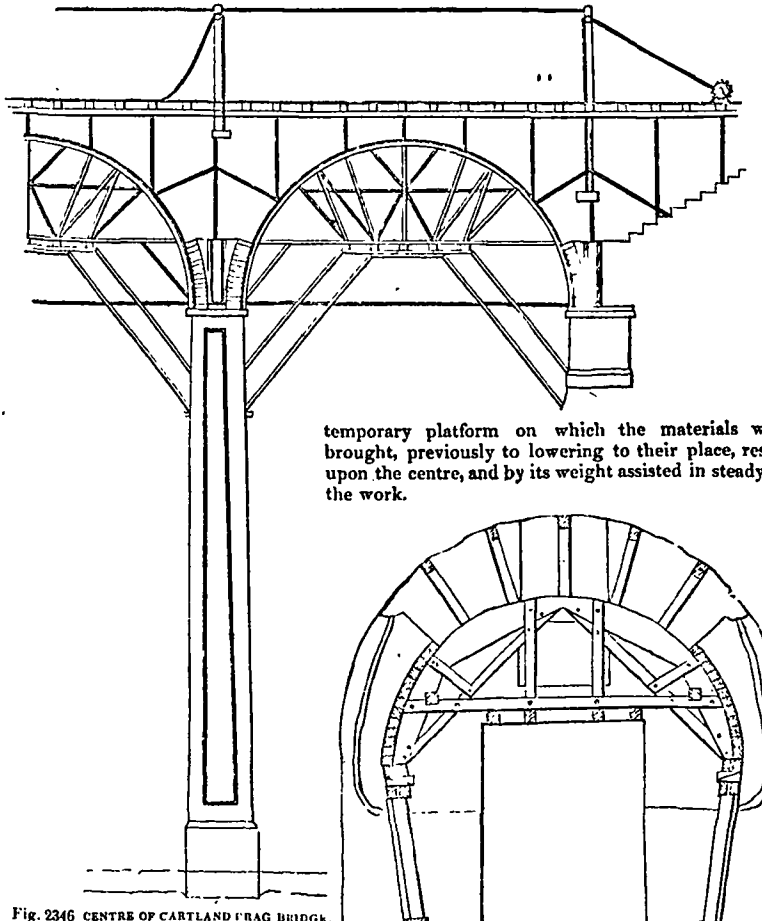


Fig. 2346 CENTRE OF CARTLAND CRAG BRIDGE.

Centres made use of for Tunnelling do not require to be always timbered throughout; although as much or greater care is necessary for their

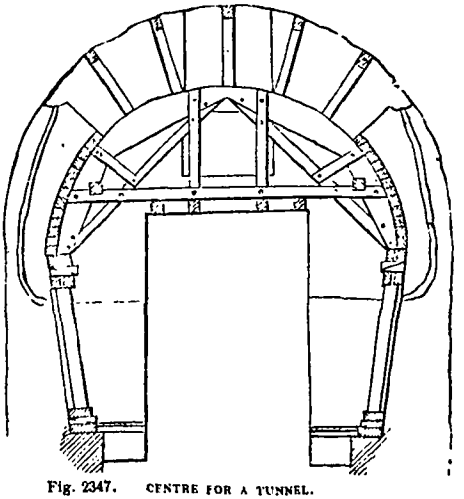


Fig. 2347. CENTRE FOR A TUNNEL.

formation as for those employed in the construction of the arch of a bridge. When the width of the tunnel and the earth which is to be removed will permit, a way may be driven on each side, and a portion of the earth or rock left in the middle, or at the two sides, upon which the timber centre may rest until the entire arch it is intended to support is completed. many tunnels have been cut through the chalk hills, with a parabolic curve given to their centres, two masses of chalk having been left to support their lower timbers.

In the former portion of the work, we have given the design and description of the centres used at many of the bridges erected during the last century, and to them we must refer the reader; those used for the construction of the bridges of London and Waterloo are particularly worthy of observation.

On Pitot's manner of determining the Strength and Power of Centres.— One of the first considerations he gives this subject is to determine the effort which the centre will have to make, in resisting the pressure at its various parts; or what it will have to bear, at different portions of time, whilst the voussoirs are fixing; the centre not being at all times equally loaded, the dimensions of the timbers must be proportioned to the burdens placed upon them, and this often before the load is equally distributed.

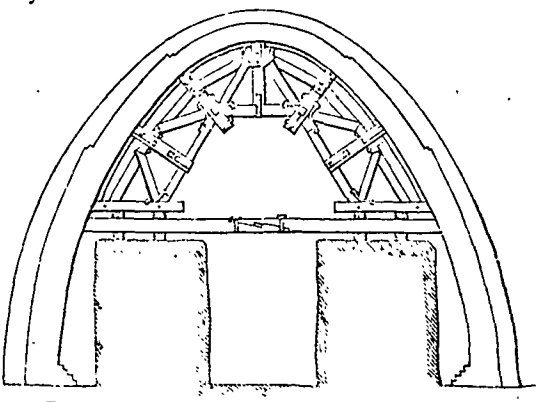


Fig. 2348. CENTRE FOR A TUNNEL.

M. Pitot has calculated the scantlings of the timber ribs for a semicircular arch 60 feet span, the stone ring that formed the first row of voussoirs being 7 feet in thickness. The timber was oak, and he states that a square inch will carry 8640 pounds weight with perfect security and for any length of time: but as knots and shakes may occur, in order to be on the safe side, he only calculates upon 7200 pounds as the measure of absolute strength. The entire weight resting on each rib or principal was 707,520 pounds, the weight of a cube foot of stone being 160 pounds. M. Pitot has in this case assumed a much more considerable weight than could occur in practice, as no arch of such a span could ever require a depth of voussoirs equal to what he has given. In a semicircular arch the voussoirs would not deposit much or any weight upon the centre, until the joints began to form a greater angle than 30°, as before observed; consequently the pressure on each rib would be diminished at least three-fourths of the entire load, and 555,908 pounds of stone would be the quantity resting on one rib, or eleven parts out of the entire fourteen.

The dimensions of the timber forming one of the ribs were as follow: the exterior curved rib, cut to the form of the intrados, was in several lengths, no part less than a foot in width, and the whole 6 inches thick, all framed and bolted together; the main stretching piece or horizontal tie-beam, as well as the under one, were each 12 inches square: the king-post 12 inches square; the upper struts 10 inches by 6, and the lower 10 inches by 8; each rib has to carry 555,908 pounds, or $\frac{1}{14}$ of the entire weight of the stone ring, and as the lower portions of the arch on each side were nearly perpendicular, the curved outer rib would have to bear 7200 pounds weight on every square inch of sectional area. The scantling being 12 inches by 6, the area is 72 square inches, and this multiplied by 7200 gives 518,400 pounds as the quantity of support that each end of this timber will afford: the lower struts will, after the same calculation, sustain 576,000 pounds; their inclination has not been considered, as it does not materially affect them.

We shall find that the strength of the outer rib, or timber ring of this centre, will have a power of sustaining 1,036,800 pounds; and if we add to this 576,000 pounds for each of the four lower struts, we shall obtain 3,340,800 pounds strength to support a load of 555,908 pounds. But as this load does not press perpendicularly on the supports, it is necessary to carry the investigation further, and to determine the value of the oblique forces, by reducing them to a parallelogram, with sides proportionate to each force, and thus acquire the exact result. To do this a scale of equal parts may be set out, from which may be taken the lengths of such sides as are proportionate to the existing forces, and then measure the results by the same scale; the scale should be divided

into parts representing 576,000; this must be set off upon each of the lower struts, to express their sustaining force, which is shown by the dotted lines at, as; and as the exterior strut receives some assistance from the outer arched rib, to the extent of 518,400 pounds, we must set off this quantity in continuation of these lines from t to e, which will form one side of the parallelogram ae; the other side will be as. The parallelogram is to

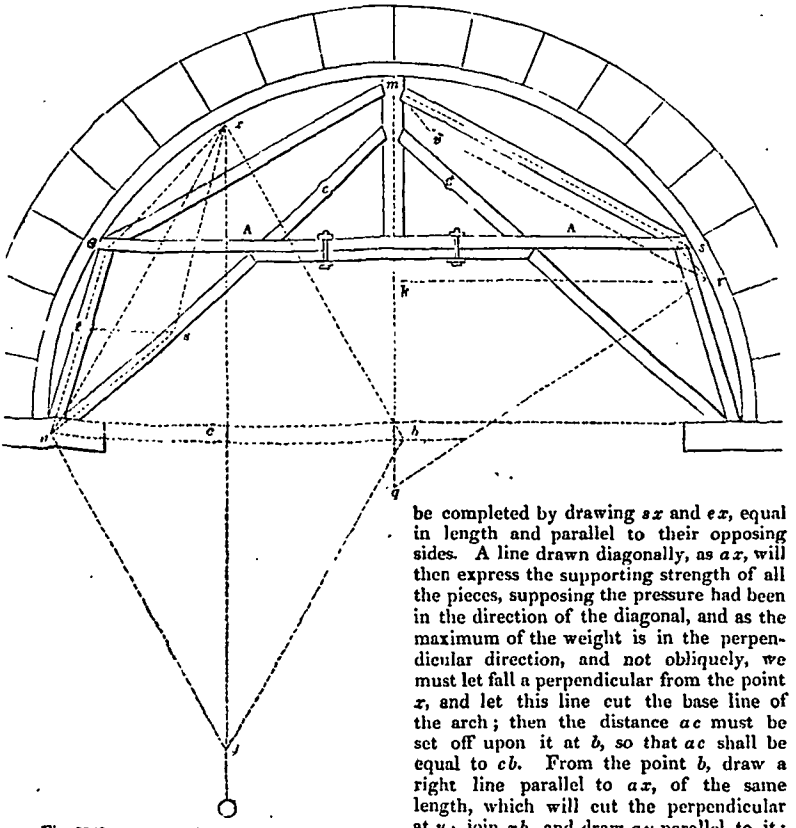


Fig. 2319. PITOT'S SYSTEM.

be completed by drawing sx and ex, equal in length and parallel to their opposing sides. A line drawn diagonally, as ax, will then express the supporting strength of all the pieces, supposing the pressure had been in the direction of the diagonal, and as the maximum of the weight is in the perpendicular direction, and not obliquely, we must let fall a perpendicular from the point x, and let this line cut the base line of the arch; then the distance ac must be set off upon it at b, so that ac shall be equal to cb. From the point b, draw a right line parallel to ax, of the same length, which will cut the perpendicular at y; join xb, and draw ay parallel to it; the parallelogram $axby$ will be completed, and xcy is a vertical diagonal, the proportionate length of which will express the strength of the rib; this upon the scale will be found to be 2,850,000 pounds, making the centre equal in strength to more than four times that required for the load it has to support. All the timbers in the upper part of the centre may have their strength calculated in the same manner as we should proceed for a pair of principals with a king-post, making due allowance for the extra support given to a centre by the outer arched rib, which does not exist in a roof. The force of each strut being taken at 432,000 pounds, and that of the curve at 518,400, we must draw two lines from the middle of the top of the king-post, viz. mv, parallel to the lower strut c, making its length equal to 432,000, and the second line, upon the upper strut ms, must also have a similar length added to 518,000, or 950,000 pounds given to it. Complete the parallelogram $msrv$, and draw the horizontal line rk, from the lowest point of the parallelogram, cutting the line mq in k, and make kq equal to km; then mq will represent the weight that can be carried by the upper portion of the centre, which will be found equal to 1,160,000 pounds, greatly exceeding the strength required. The chief part of the load is sustained on the upper portion of the centre, therefore it requires that the struts should have had a greater scantling than the lower, although there is abundant strength throughout. The strain of the stretching-piece A A is denoted by rk and mq, which is the actual load sustained by the upper portion of the centre; one-sixth part or less of the strength of the cohesion of this stretching-piece is sufficient for the horizontal thrust to which it is exposed.

These researches were made in the year 1726, and inserted by Pitot in the memoir of the Academy; they are founded on the hypothesis that the voussoirs are very numerous, and capable of sliding without any friction; consequently Pitot has valued the weight, therefore, which rests on the centre as too high.

Couplet has also examined the weight supported by centres, in his memoir of 1729: referring to arches composed of polished voussoirs, he remarks, and with reason, that on each side, starting with the springing, there is a certain number of voussoirs, which do not bear any weight upon the centre; and seeking the length of the arc embraced by these voussoirs in the semicircular vault, he finds it equal to the third of a quarter of a circle, a result which, being independent of the thickness of the arch, could only be exact in a particular case. With regard to the relation between the load which the upper part of the arch makes the centre support and its absolute weight, Couplet arrives at a result different from that of Pitot, and points out the error into which this latter had fallen: we will not enter further into these details, the inaccuracy of which is generally acknowledged.

It is known that in an arch extradossed the first courses support each other, without the assistance of a centre, so that it does not receive any load from it, until the plane of the joint makes with the horizon an angle, the trigonometrical tangent of which is equal to the relation of the friction to the pressure. It appears that when the voussoirs are placed on wedges, and laid dry over each other, this relation should be equally valued nearly as 0 is to 8, whence it results that the voussoir which begins to make the centre experience a certain pressure should have the plane of its joint inclined about 42° to the horizon: as to the value of this pressure, which acts perpendicularly to the surface of the centre, calling a the angle of inclination of the plane of the inferior joint, m the weight of the voussoir, f the relation of the friction to the pressure, it will be expressed thus,

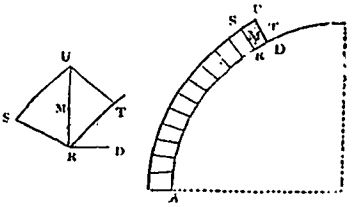


Fig. 2350.

$$m\,(\sin.\ a - f\cos.\ a)$$

The weight of the centre may be valued by calculating the value of this expression, for the different courses which shall be successively placed, until we arrive at a voussoir, M, so inclined that the vertical passing by its centre of gravity falls on the edge, R, of the voussoir immediately beneath it. There then happens one of two things, if the angle T R D, formed by the surface of the centre with a horizontal line D R, be less than 42 degrees, the voussoir M will sustain itself on the centre, without leaning on the inferior voussoirs; but if that angle be greater, the inferior voussoirs will carry a part of the weight of the voussoir M. It is easy to convince ourselves that the latter of these two cases hardly ever occurs, and that the first is the only one necessary to take into consideration. Starting from the voussoir M, the load of the centre may be estimated by the entire weight of the voussoirs: the position of the voussoir M depends moreover on the curve of the vault, and on the relation of the dimensions of the voussoirs,

Let us suppose that the head of the voussoir M be a rectangle, U R will be the vertical passing by the centre of gravity, and the triangles U R T and T R D being similar, we shall have tang. $\mathrm{T\,R\,D} = \frac{\mathrm{R\,T}}{\mathrm{T\,U}}$: but if the angle T R D be the angle of friction, the tangent of this angle will be $=0{\cdot}8$; then we shall have also, $\frac{\mathrm{R\,T}}{\mathrm{T\,U}} = 0{\cdot}8$, that is to say, that the width of the voussoir will be $\frac{8}{10}$ of its length. Now the width of a voussoir, in large arches, is at the most only $\frac{1}{4}$ or $\frac{1}{5}$ of its length; consequently the angle T R D will be less than the angle of the friction; but if in the first moment the voussoir M, and those which follow it, do not exert any action on the inferior voussoirs, it is not the case when the settling of the centre takes place. As this settling cannot continue without obliging the arc A S (fig. 2351.) to become shorter, this arc resists, as a portion of the arch, the pressure which exerts itself at its superior extremity; as long as that pressure is not strong enough, it preserves its form and position; it is the voussoirs situated above M which yield by spreading, but as soon as there is placed above M a sufficient number of courses for their stability to be superior to the resistance of the portion of the arch A S, this latter breaks in two parts, which tears the centre asunder; two points of rupture are the result, at the extremities A B and R S, and a third at a certain point, such as K L, the position of which latter joint is determined by the condition that the momentum of stability of the two parts A L and L R, taken with relation to the point B, be equal.

When an arch is constructed at the moment the rupture takes place, and the arc A S re-

moves itself from the centre, the first joints of the extrados towards the point L are seen to open, and this effect continually augments with the settlement of the centre, until the placing of the keystone; then the effects change their nature, because the voussoirs of the upper part being able to sustain themselves, without the assistance of the centre, the equilibrium tends to establish itself in the entire arch, and no longer in the portion A S. The point of rupture is then no longer situated in K L; it rises higher, and therefore at this period the first joints, which had opened at the extrados, are closed, and others open at joints farther removed from the springing. It is now evident that the lower part A R of the centre will find itself entirely disengaged, but that the part R C, besides the weight of the voussoirs R, X, will still support a certain pressure, resulting from the thrust of the rampant arch A S: it will be easy, knowing the weight of the portion K S, to have the value of that pressure which will be directed, following the line S F perpendicular to the joint S R, which will meet the vertical in F, passing by the common centre of gravity R X; then, supposing the pressure which exerts itself according to S F, and the weight of the voussoir R X, applied at the point of meeting, F, of their directions we should take the result of these two forces, which will be directed, following a line such as F H, and will represent the total burden supported by the centre: an equal force will be furnished by the other half of the arch.

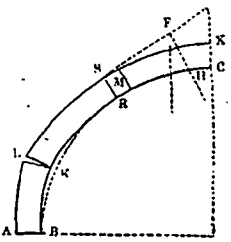


Fig. 2351.

The effects alluded to are equally evident in a semicircle, or the segment of any kind, unless the latter is so flat that the first voussoir from the springing leans entirely on the centre; in this case the weight of the centre is due solely to the weight of the voussoirs, and the calculation of this weight becomes simple, and may be readily continued for every period of the construction; thus the first part of the study is resolved by considerations, exactly agreeing with the observations and experiments that have been made, and form a necessary addition to our knowledge on the theory of arches.

The forces which act on the centre at the different epochs of the construction being known, it will be very easy to determine the loads supported by the different pieces of carpentry, whether parallel or perpendicular to their length, and it would only remain to proportion their dimensions to these loads. Gauthey has given an example of this kind of calculation, which he has applied to the bridge at Nemours. The effort of the weight of the arch is transmitted first to the first row of inclined timbers, but the pieces of which it is composed, slanting very little towards each other, can scarcely offer any resistance; the slightest settlement carries back the weight on the second and third rows, so that the first must be considered as destined only to receive the voussoirs, and to transmit their weight to the pendant binding-pieces: by observing that the principals of the centres support 2·05 metres of length of arch, that the specific weight of masonry is 2·6, and having regard to the different heights of the section of the voussoirs carried by each binding-piece, it is found that the weight of the binding-piece *a b* is 18,789 kilogrammes, and that of the binding-piece *g h* is 14,696 kilogrammes.

We must remark that each of these binding-pieces bears on the meeting of two pieces of one of the lower rows of inclined timbers, and on the middle one in the other row: now if the pressure acting on the binding-piece *a b*, (fig. 2341.) for example, cannot fail to make the piece *c d* bend, and greater strength would be obtained than by augmenting the angle of the two pieces *b e* and *b f*, though it is not possible to know precisely what part of the weight carried by the binding-pieces is supported on one side by the piece *c d* and on the other by the pieces *b e* and *b f*, because this in part depends on the settlement of the centre and the goodness of the framing: it is evident that these two last pieces will carry almost the whole, and in the impossibility of regulating exactly the manner in which the weight is distributed, the most natural and the nearest to the truth consists in supposing it is supported entirely at the point *b*, that the piece *c d* does not carry any weight, and that it has no other effort to sustain but the pressure which it exercises in the direction of its length: it is always easy to render the work conformable to this supposition, by leaving a little play in the notch of the binding-piece at the meeting of this piece. Naming P the weight supported by *a b*, *p* its composante following *b e*, *p'* its composante following *b f*, *a* the angle *e b f*, C and Y the angles formed by each of the pieces *b e* and *b f* with the vertical, we shall have

$$p = P\frac{\text{sin. Y}}{\text{sin. } a}\,;\; p' = P\frac{\text{sin. C}}{\text{sin. } a}\,:$$

making in these equations P = 18,789 kilogrammes, and putting for the angles *a* C Y the

values which suit them, according to a formula given by Boistard for this centre, and which makes $a = 191{\cdot}09°$, $C = 75{\cdot}37°$, $Y = 115°$, we shall find $p = 128{,}730$ kilogrammes, $p' = 124{,}730$ kilogrammes. In the same design the length of the piece bc is 3·41 metres, that of the piece bf is 4·28 metres, and their square is 35 centimetres: making then in the equation

$$Q = (20336845 + 21017476\ bc)\ \frac{a b^2}{c^2},$$

$a = b = 0{\cdot}35$ and $c = 3{\cdot}41$, we shall find for the weight which would begin to make the piece be bend, $Q = 16{\cdot}7480$ kilogrammes: and making in the same equation $C = 4{\cdot}28$, we shall find for the weight which would begin to make the piece bf bend, $Q = 121{,}400$ kilogrammes: thus the first of these two pieces is a little stronger than is necessary, and the second would be too weak, if, as we have supposed, the pressure transmitted by the binding-piece ab were entirely carried on be and bf.

In seeking in the same manner what portion of the load transmitted by the binding-piece gh is supported by the pieces cd and di, we shall find that the pressure exercised according to di is equal to 4149 kilogrammes, and that the pressure which exerts itself according to cd is equal to 44,020 kilogrammes: thus the load of di is scarcely the third of that of bf, and as the length of the two pieces is the same, the square of di might be less than 35 centimetres; cd is also much less loaded than bc, but its length, which is 5·85 metres, is more considerable. In making in the preceding equation $a = b = 0{\cdot}35$, and $c = 5{\cdot}85$, we shall find $Q = 79{,}380$ kilogrammes: notwithstanding, then, its greater length the piece cd is stronger than is necessary: thus we may conclude that of all the inclined timbers, regard being taken to the pressure compared with the length, bf is that which supports the greatest effort; that 35 centimetres square is rather small for this piece, but a little too large for all the others.

Scaffolding requires as much care in the selection of the timber employed, as for that which is to constitute a part of the edifice: generally a scaffold is composed of upright poles, and ledgers laid horizontally and secured by strong cords; on the latter is laid the ends of shorter poles or putlocks, which have a bearing on the wall of the building in holes left in the masonry purposely to receive them: for churches and public buildings a double scaffold is employed, which is braced in several directions, and, where round poles are not obtained of sufficient strength, squared timber is made use of. The example given was erected by M. Dubrin, master carpenter, before the façade of Saint Gervais at Paris, and was found to answer its purpose admirably: where the walls are to be carried up to a considerable height, it is requisite to spread the base of the scaffold, and to introduce additional braces.

Scaffolding used in the erection of the Monument, by Sir Christopher Wren, occupied a square, the side of which was 60 feet, and as there was a double row of poles, it left an interior square, the side of which was 35 feet, in the middle of which the Monument was constructed. The entire width of the scaffold was therefore 12 feet 6 inches all around it, and at each angle of the inner and outer square was placed two poles, pitched upon the diagonals of the square: between these, in the middle of the length of the outside, were three poles, and between them and the angle two others; each side of the inner square was divided into two, by two upright poles, so that there were 36 standard poles on the outside, and 16 on the inside, in all 52, which were continued up, with a slight inclination, to the height of 120 feet, after which single poles were found sufficient to construct the remainder of the scaffolding to the top: 28 ranges of ledgers were fastened to these upright standards, at distances of 8 feet; those continued round the interior and exterior, forming as many stories, and supported the putlocks or cross timbers, on which the planks were laid; diagonal braces, each of which crossed four stories, were secured firmly on all sides, to the ledgers, from the foundation to the summit, to which a well-contrived wooden stairs enabled the workmen to mount and descend.

The Scaffolding for the Nelson Column in Trafalgar Square was designed and executed under the direction of Mr. Allen. The whole was composed of unsawn timber, and the total height was 180 feet; 154 loads of timber, or 7700 cubic feet, were made use of, and the cost of its erection was 240*l*. The upright timbers were slightly tenoned into the horizontal, and where the joint was made, iron dogs were driven into the timbers in a diagonal direction across the joints; these afterwards were easily withdrawn, and the timber but little injured: the base of the scaffold was 96 feet square, without measuring in the raking braces; there were in all seven stories, which diminished in height from 48 feet to 21: the whole was strengthened by flying wind-braces, which were supported by cross transoms, which projected outwards about 6 feet from the perpendicular of the scaffold at each stage: at the summit worked a travelling machine, by which one mason could set as much work in a day as was formerly done in three.

At the London and Birmingham Railway Station, Euston Square, Messrs. Cubitt contrived

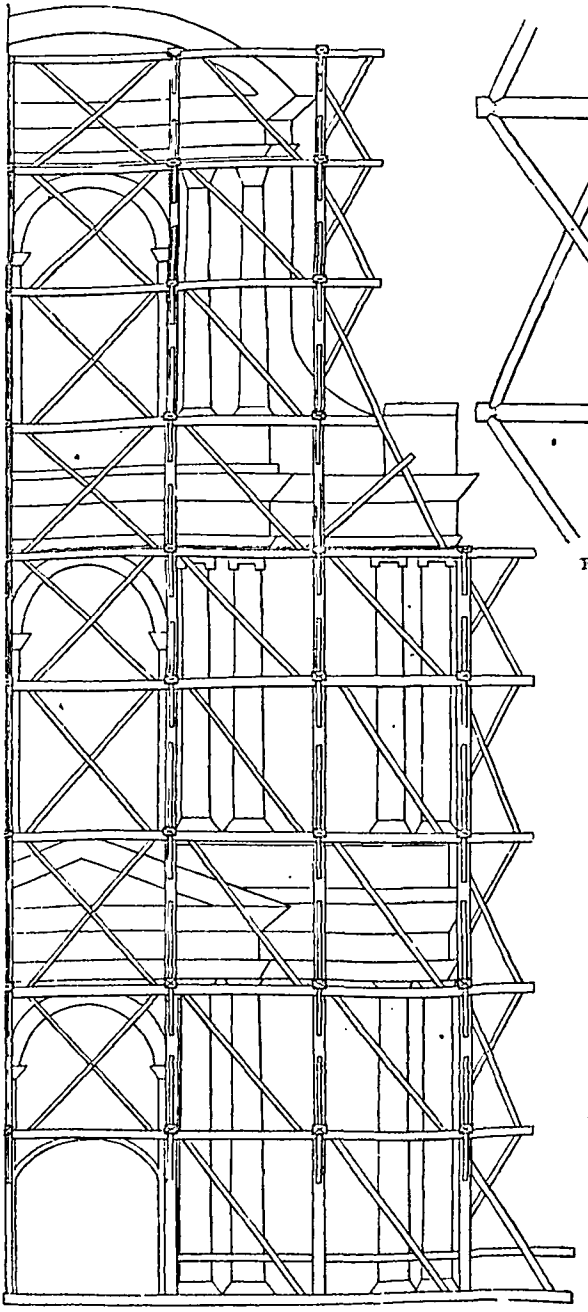


Fig. 2352. SCAFFOLDING.

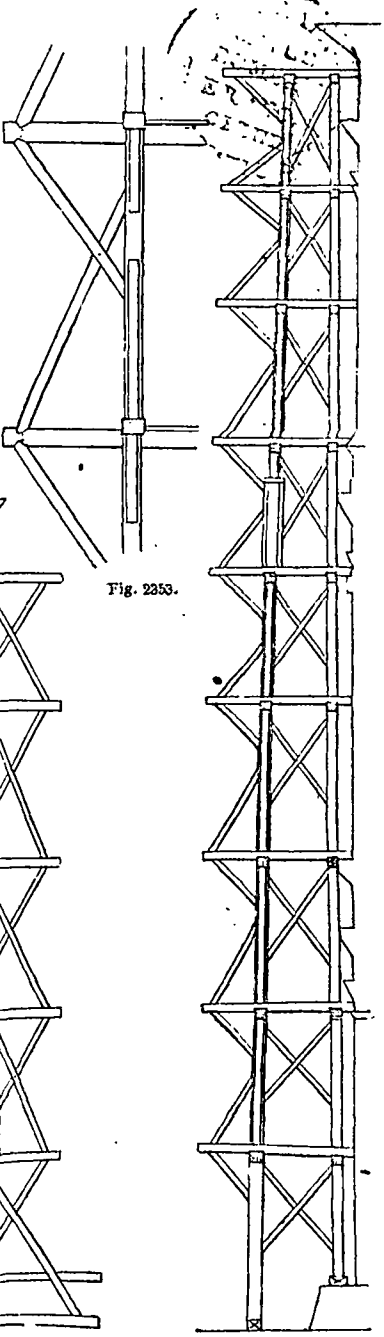


Fig. 2353.

Fig. 2354. SECTION.

a scaffold, with two parallel rows of standards, 50 feet in height, and about 17 feet apart, which were all diagonally braced: after the building had advanced to this height, another

similar arrangement was made, and the whole was raised to 90 feet; the materials were all hoisted by travelling trucks mounted on tram-ways laid down for the purpose. Square timber is decidedly preferable to round poles for the purposes of scaffolding, as there is comparatively little waste incurred; and the timber, being thoroughly seasoned by exposure, is benefited rather than injured by its application to this purpose. The travelling winch on a frame is now universally adopted; where 10 or 15 tons are to be hoisted at a time there would be great economy in the employment of steam-power.

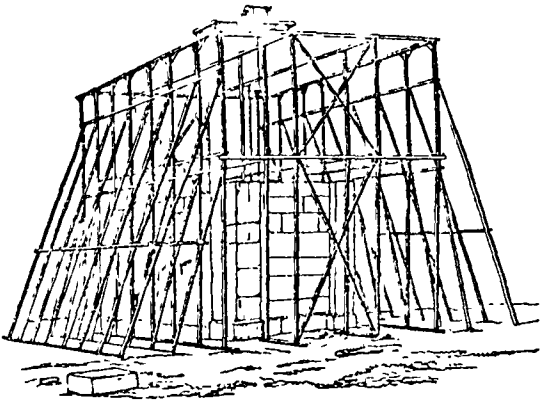


Fig 2355. SCAFFOLDING OF EUSTON SQUARE STATION.

When poles or squared timbers are employed in an upright position, as they are in a scaffold, the force that would bend them when acting in that direction must be exactly calculated, for if bent in the slightest degree, any additional effort will cause fracture. The strain is always directly as the weight or pressure, and inversely as the strength, which is also inversely as the cube of the diameter: it is also directly as the deflexion, which will be directly as the quantity of angular motion, and as the number of parts strained; that is, directly as the square of the length, and inversely as the diameter.

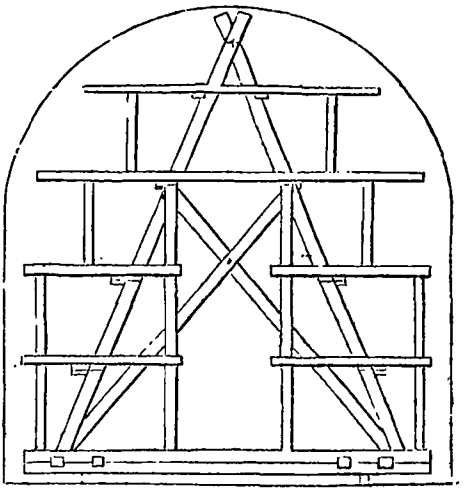


Fig. 2356. SCAFFOLD USED AT TURIN.

The stiffest rectangular post is that in which the greatest side is to the less as 10 is to 6, but this will bend in two directions, and braces and struts must be introduced in a position to prevent any change of form: the ledgers of our ordinary scaffolds being secured by cords to the upright standards, at distances of 5 feet or more apart, prevents any bending of the latter, the cord passing round both the horizontal and vertical pieces, so that it secures the two firmly together, supporting them against each other in those parts where they would most probably yield to the weight they have to sustain. The expert scaffold-builder makes his knots so that the horizontal poles or ledgers form a series of struts or straining pieces, and prevent the standards from yielding under any weight.

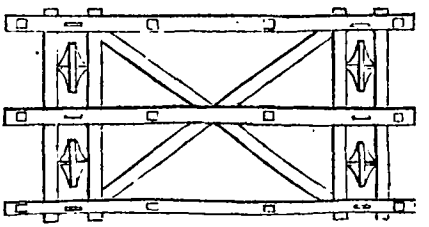


Fig. 2357. PLAN OF SCAFFOLD.

The Scaffold made use of at a chapel at Turin in Piedmont, for cutting the caissoons in the vault, which was cylindrical, was well adapted for its purpose, and by means of wheels, the position of which are shown in the plan, it could be moved either forwards or backwards.

A similar scaffold was contrived by M. Mandar, the architect, at Paris, for the construction of a roof erected under his direction, on the principles of Philibert Delorme; it was com-

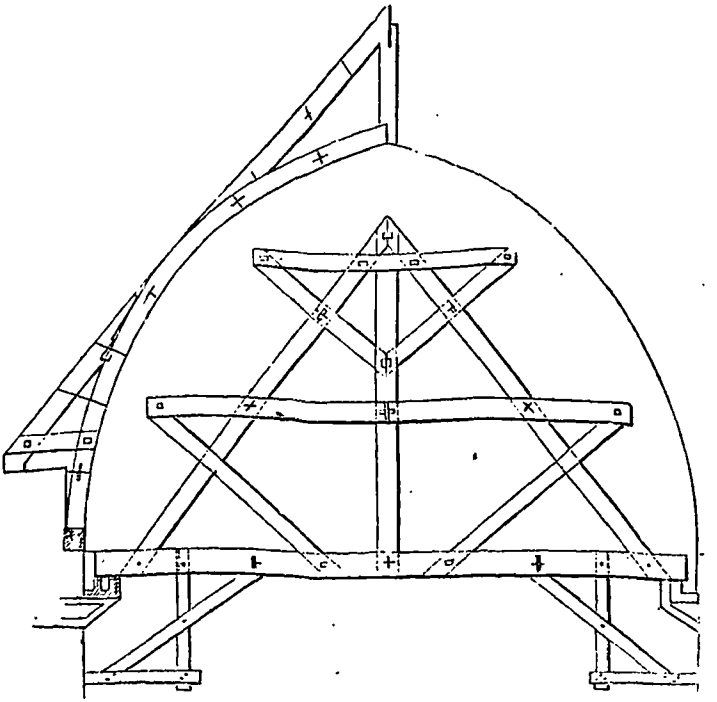
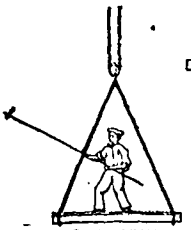


Fig. 2358. SCAFFOLD DESIGNED BY MANDAR.

posed of three frames or floors, supported upon braces and portions of St. Andrew's crosses: it was so light that it could be moved with facility by means of copper wheels.

A suspended scaffold for a single workman is easily contrived by ropes and pulleys, and is frequently used by painters: where the cornice has sufficient projections, as at St. Peter's at Rome, a pole may be suspended, into which a brace may be pinned with its end lodged on the architrave below; such a pendant scaffold requires to be well secured at top, either by loading it or pinning it down.



SUSPENDED SCAFFOLD.
Fig. 2359.

In all suspended scaffolds, we must regard the timber employed as pulled in the direction of its length, and the quantity of space through which it extends is directly proportional to the number of parts extended, and to the weight. Emerson says that a piece of oak 1 inch square, and 1 foot long, supported at both ends, bears 315 pounds before it breaks, and the same will bear, when drawn in the direction of its length, 2835 pounds, or 1¼ tons. We have not sufficient data to enable us yet to decide upon the strength of the timbers in the situation we are now considering, when drawn in the direction of their length; but the extension to which they are subjected is inversely proportional to the area of the section, or inversely as the breadth and thickness.

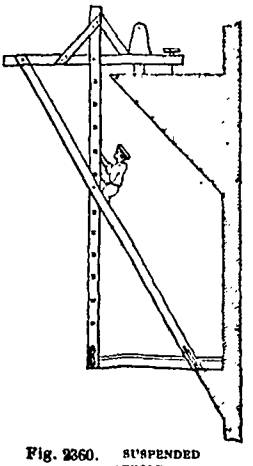


Fig. 2360. SUSPENDED SCAFFOLD.

Suppose L the length in feet, W the weight in pounds, B the breadth in inches, and T the thickness in inches, then $\frac{L \times W}{B \times T}$ is the extension; or, when the extension is given, $L \times W : B \times T$. Where a is a quantity derived from experiment, then $a = \frac{B \times T}{L \times W}$.

To Nicholas Zabaglia, who was born at Rome in 1674, we are indebted for designs of some of the best scaffolds that have been erected. This celebrated mechanic, first employed at the Vatican as a carpenter, afterwards became the chief director of the works at St. Peter's: Jean Bottari, the librarian of the Vatican, collected several of his designs for scaffolding, which are published under the title of "*Castelli e Ponti di Nic. Zabaglia, con alcune ingegnose pratiche, e con la Descrizione del Trasporto del Oblelisco Vaticano e di altri del Dom Fontana*, 1743." In one of the plates the scaffold-builder is represented in his workshop examining the force of a pulley, and of the fifty-four, thirty-six are designs of various machines to assist in construction; they are exceedingly interesting, and should be in the possession of every civil engineer. Caylus considered the talents of Zabaglia as of a very superior kind, and Passeroni commemorated them in his poem called "*Il Cicerone.*" In the construction of the scaffolding at St. Peter's, he made use of the holes left in the vaulting, for the purpose of suspending, by means of iron rods, platforms, upon which the workmen stand to clean or re-colour the soffites.

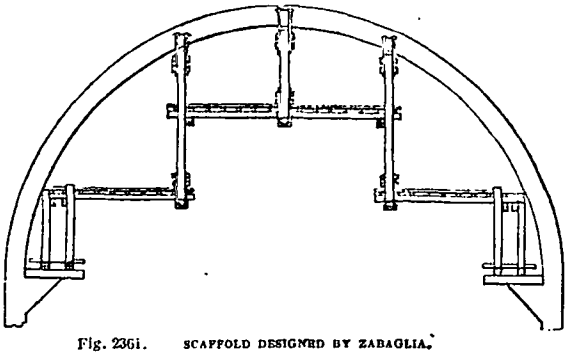


Fig. 2361. SCAFFOLD DESIGNED BY ZABAGLIA.

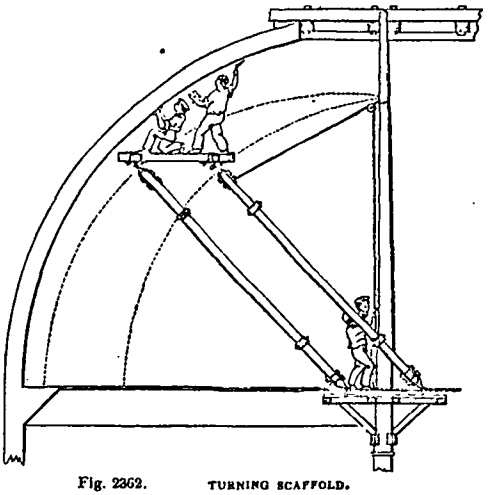


Fig. 2362. TURNING SCAFFOLD.

Turning Scaffolds may be attached to a revolving pole with two arms, acting like the radii of a circle, which may be raised or lowered at pleasure: these arms carry a platform attached by iron hooks, on which stand the workmen; by means of ropes and pulleys

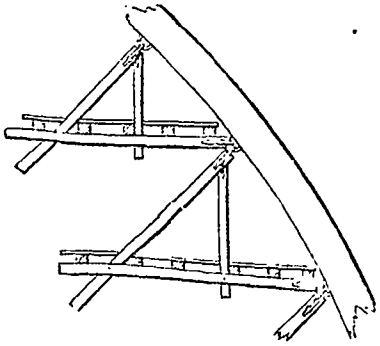


Fig. 2363. TURNING SCAFFOLD.

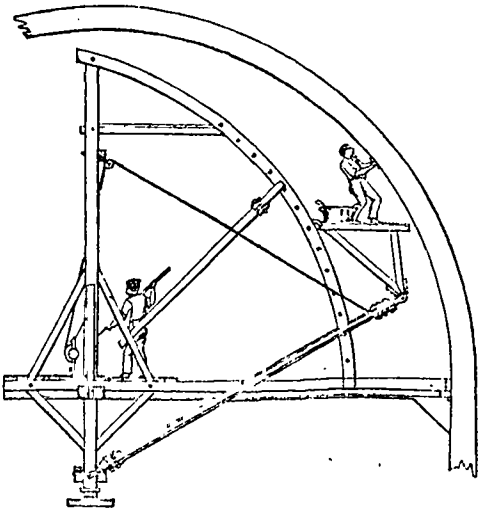


Fig. 2364. TURNING SCAFFOLD.

it can be placed in any required part of the vault. Turning scaffolds are rendered more steady when the lever which supports the workman is elevated at the side of a quadrant, to which it may be secured at the height required.

Some scaffolds are made with a number of floors; the most simple are those suspended from holes in the vault.

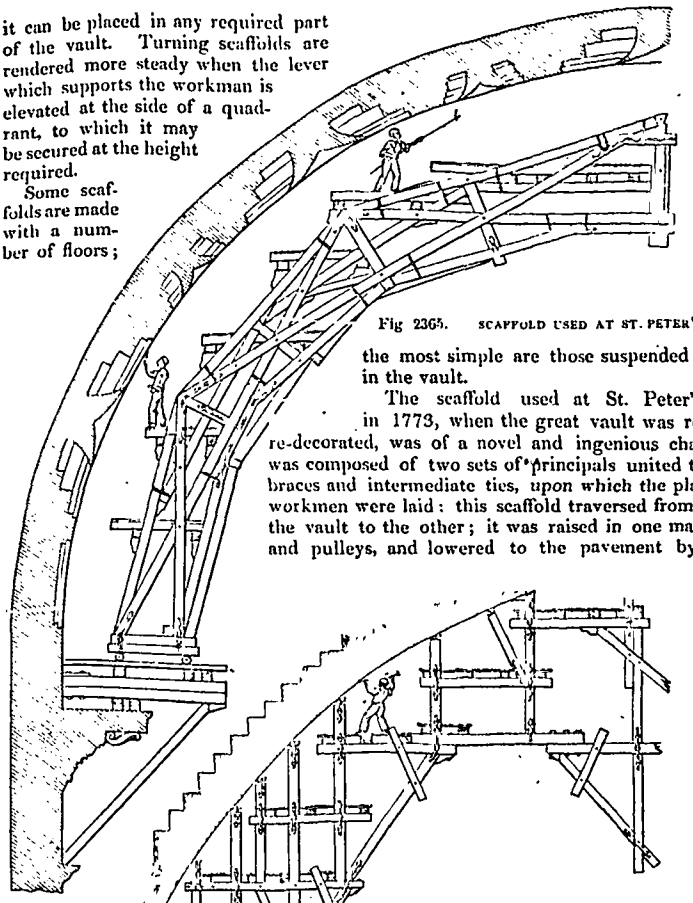


Fig 2365. SCAFFOLD USED AT ST. PETER'S.

The scaffold used at St. Peter's at Rome in 1773, when the great vault was repaired and re-decorated, was of a novel and ingenious character. It was composed of two sets of principals united together by braces and intermediate ties, upon which the planks for the workmen were laid: this scaffold traversed from one end of the vault to the other; it was raised in one mass by ropes and pulleys, and lowered to the pavement by the same means when the work for which it was destined was completed, the ropes were passed through the holes left in the vaulting for the purpose. The editor cannot omit the opportunity of bearing his testimony to the skill and ingenuity of the Italians in making scaffolds for the most temporary purposes: when engaged in taking the casts and measurements of various remains in the Imperial city, the ladders and scaffolds prepared by the workmen for his use were of the most perfect kind: although light, and apparently fragile, he often mounted upwards of 100 feet, and remained the whole of the day at his work, without the slightest risk of accident.

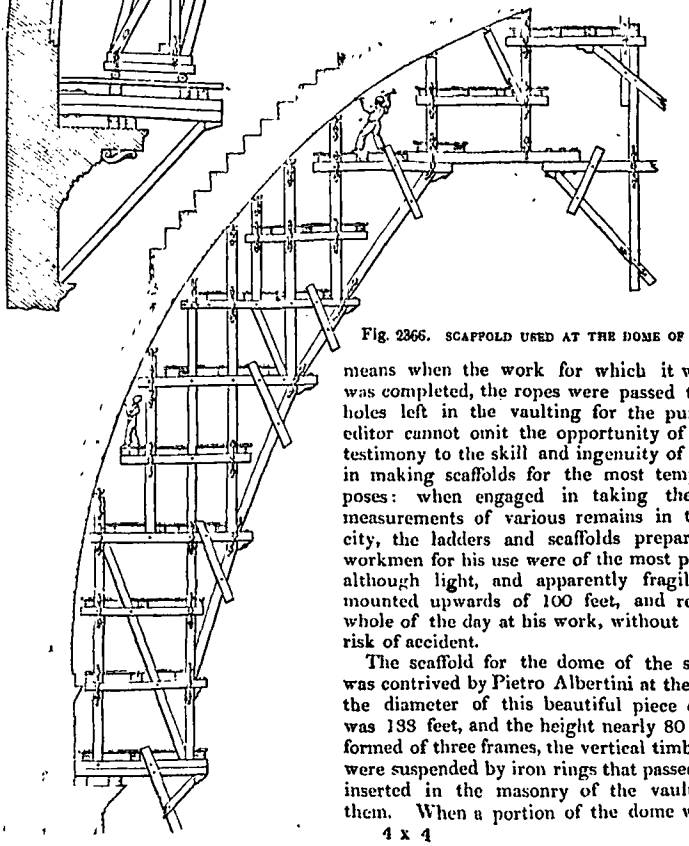


Fig. 2366. SCAFFOLD USED AT THE DOME OF ST. PETER'S.

The scaffold for the dome of the same church was contrived by Pietro Albertini at the same time: the diameter of this beautiful piece of carpentry was 133 feet, and the height nearly 80 feet: it was formed of three frames, the vertical timbers of which were suspended by iron rings that passed over hooks inserted in the masonry of the vault to receive them. When a portion of the dome was repaired

the position of one of the sets of principals was transferred to the other side, without deranging the two, which served to make the alteration in the scaffold without danger.

The scaffold contrived by Campanarino for the restoration of the dome of the Pantheon at Rome rivalled all others in the beauty of its design and delicacy of its execution: it was composed of two principals, an elevation of which with the braces is shown below. At the summit, through which the only light is admitted into this magnificent rotunda, a stout timber curb was fixed, in the centre of which was the pivot upon which the upper part of the scaffold revolved: the lower end rested on the bold projecting cornice beneath the coffered dome, and by means of pulleys a small power could advance the entire scaffold; these were also attached to various parts for the purpose of hoisting the materials to their required situations: iron ties and braces were introduced to prevent any springing, rendering the whole perfectly steady, and admirably adapted for its purpose.

This noble building is internally 143 feet in diameter, and 148 feet 4 inches in height from the pavement; the dome which covers it may have been constructed on several such ribs, supported from below by a forest of upright timbers.

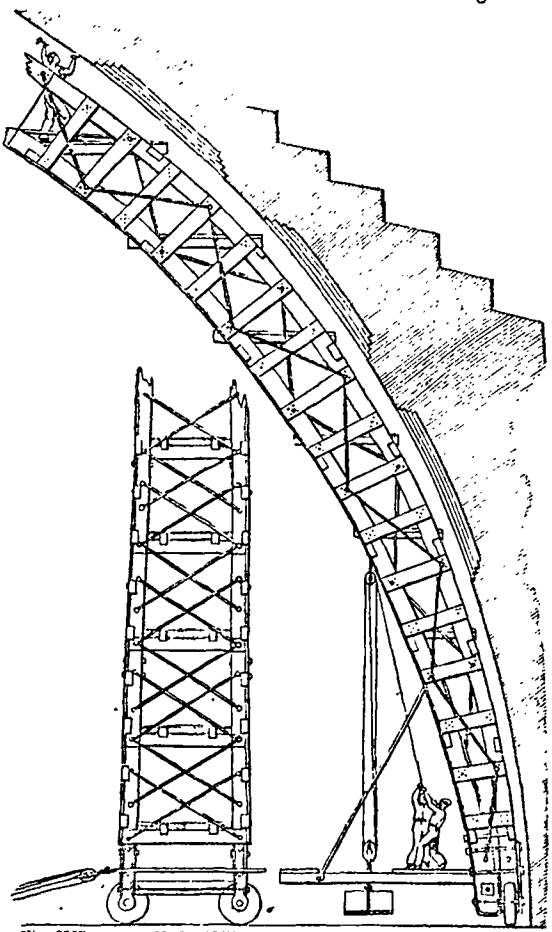


Fig. 2367. SCAFFOLDING AT THE PANTHEON.

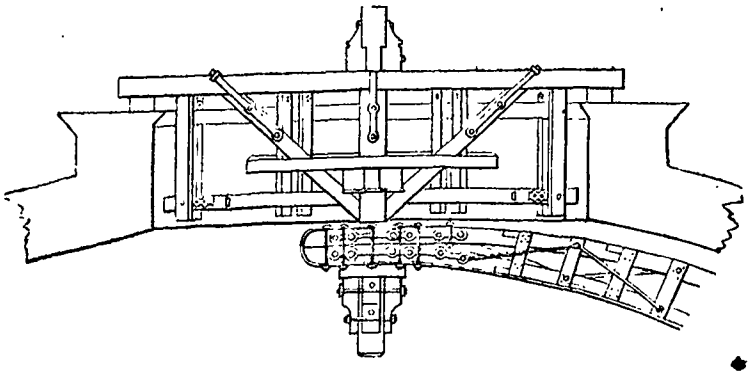


Fig. 2368. SECTION OF THE APERTURE AT THE TOP OF THE DOME.

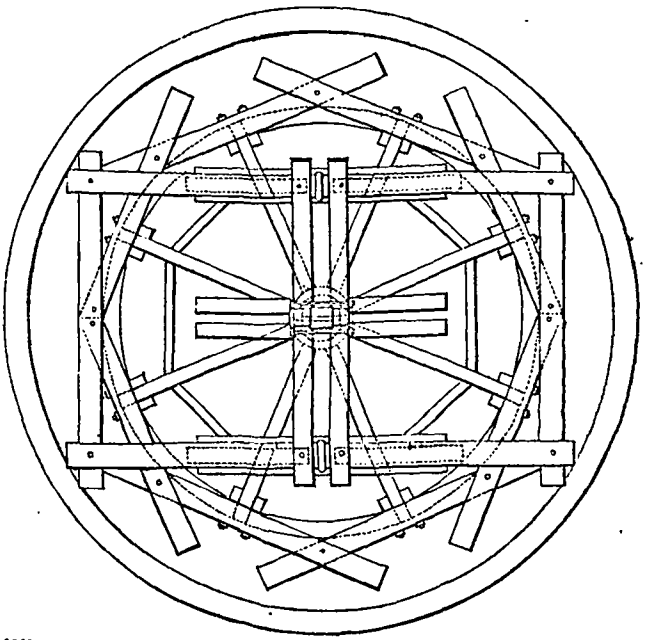


Fig. 2369. PLAN OF SCAFFOLDING AT THE APERTURE AT THE TOP OF THE DOME.

To the scaffold builder a knowledge of the variety of knots is important, and as ropes are used in several machines, it is necessary that every mechanic should understand how they can be secured and tied together.

An ordinary knot is simply made by twisting a rope twice round, and passing the ends in opposite directions.

Loop knots for joining pieces of rope together are passed through a loop in such a manner that, when pulled tight, they are firmly united: they may cross each other, or simply pass through each rope when doubled.

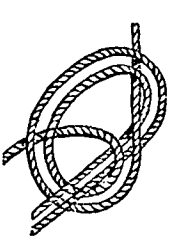


Fig. 2370.

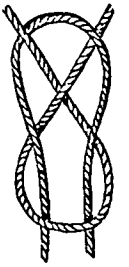


Fig. 2371.

Fig. 2372.

The wall knot is made with the lays of a rope, and cannot slip; the bow-line knot is so firm that when fastened it is perfectly secure.

The sheep-shank knot, which shortens a rope without cutting it, is so arranged that it can be readily loosened again: most knots are for the purpose of fastening one rope to another, which is effected by means of a small cord attached to the neck of the knot, and firmly tied about both ropes.

The fibres of a rope seldom exceed in length 3½ feet; they must therefore be well twisted together before they are applied: large ropes are either cable-laid or hawser-laid; the former are composed of nine strands, the latter of three, and each of a number of primitive yarns: a rope 8 inches in circumference may have 414 yarns equally divided among three strands.

The greater the obliquity of the fibres that compose a rope, the greater will be their adhesion, but the greater also will be their immediate tension, in consequence of the action of a given force in the direction of the rope; but the relative

Fig. 2373.

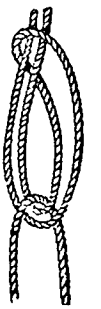


Fig. 2374.

position and comparative tension of all the fibres employed can scarcely be estimated, and it must depend in an essential degree upon the quality of the hemp or material employed.

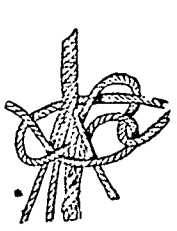


Fig. 2375.

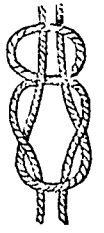


Fig. 2376.

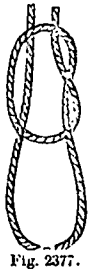


Fig. 2377.

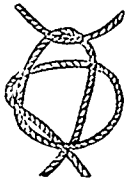


Fig. 2378.

Ropes passing through Rings may be variously secured, either by taking one end through a series of loops, or by a triple twisting through a single one. Emerson found that a good hempen rope, of 1 inch in circumference, would bear 1000 pounds weight suspended to it, whilst a rod of iron of the same dimension would support 3 tons, and another of yellow fir, 2 inches in diameter, would carry 7 tons.

The rigidity of ropes or cords, and the difficulty of bending them into any given curve, prevents the formation of a close knot, particularly where they are of large diameter: the resistance arising from this stiffness is as the weights which stretch the cords, multiplied by their thickness, and divided by the radii of curvature of the surfaces over which they pass.

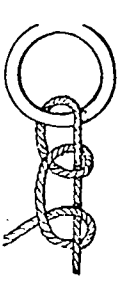


Fig. 2379.

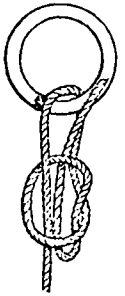


Fig. 2380.

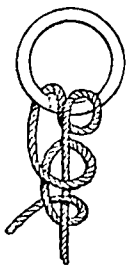


Fig. 2381.

The Scaffold Builder must form his knots or make fast his ropes in the way best adapted for his purpose: when a St. Andrew's cross is formed by two poles, to be tied tightly together, two or more ropes are lashed around them, drawn tight and made fast; a single or double loop may be passed around the head of a post according to the security required.

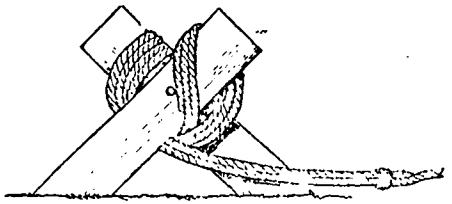


Fig. 2382.

Mariners make use of a great variety of knots which have been adopted by engineers, to secure the heads of piles or attach horizontal timbers laid against them; a double loop, or thrice twisting round, and afterwards passing the rope through a double loop, is an effectual fastening, and prevents the knot from slipping in any direction.

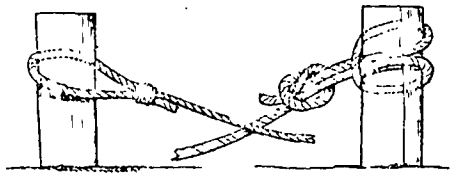


Fig. 2383.

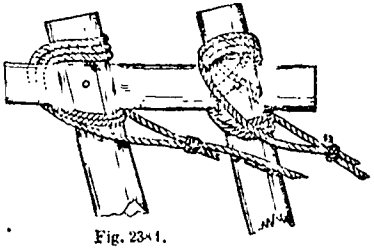


Fig. 2384.

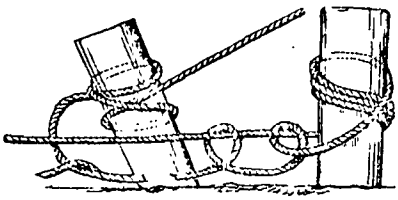


Fig. 2385.

The double loop is always to be preferred, and made by doubly twisting the rope round the pole, passing it by the loops, and drawing them tight.

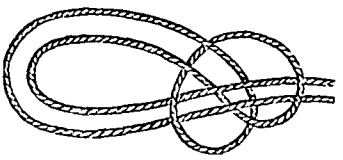


Fig. 2386.

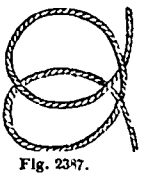


Fig. 2387.

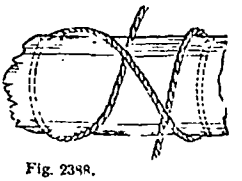


Fig. 2388.

Chains made of iron are often found more convenient in their application to machinery, consisting of a series of links riveted in the manner of a watch chain, or hooked together, as proposed by M. Vaucanson: each system, however, has its advantages and peculiar application.

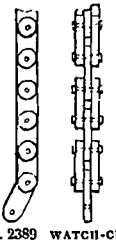


Fig. 2389 WATCH-CHAIN.

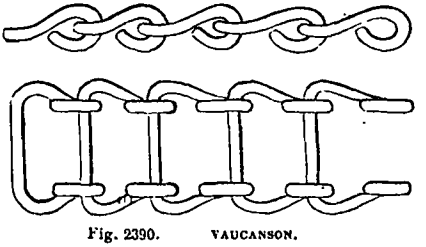


Fig. 2390. VAUCANSON.

CHAP. XXIV.

MASONRY.

BUILDING with stone is of the greatest antiquity, and it is extremely difficult to trace its origin: the Egyptians were perfect masters in the art of stone-cutting, and the Greeks exhibit such perfection in their works, that it is almost impossible to equal them; to the mason's art they added that of the sculptor, and the buildings executed in marble, still remaining, are monuments of their taste and skill. The Romans have also left much that is worthy our admiration, particularly those structures in which arches and domes of considerable dimension form the striking features: to the freemasons of the middle ages we are also indebted for many wonderful examples of their ingenuity and knowledge, of which we have ample proofs in the well-executed groined vaults they introduced, and which are unequalled for design in the structures which preceded them: they lessened the area of the points of support, balanced the thrust of their stone roofs by judiciously conceived buttresses, and evinced great skill in their adaptation.

For facing the stone our masons now make use of the point, the inch tool, the broad tool, and the boaster; the first is to form a series of narrow furrows, with rough ridges between them, afterwards to be cut away by the inch tool. The boaster is 2 inches in width, and the broad tool 3½ inches at the cutting edge. Stone axes, jedding axes, cavil or scabbling hammers are employed to bring rough stones into shape: mallets and chisels, levels, plumb-rules, bevels and squares, are also required by the mason.

The Opus incertum, formed of small stones of irregular shape, touching only at certain points, was preferred by Vitruvius to the *opus reticulatum*, not on account of its appearance, but for its superior strength; if the mortar be well composed for the materials with which the inner part of the work is filled, and the angles are protected with squared or hewn stone, a solid mass will be the result.

The Emplecton had the faces of the stones smooth; the other sides were left as taken from the quarry. Walls are often built with flint or round stones from the sea-beach; it is then necessary to protect the quoins with square masses, and to carry up the outer faces by means of frames formed of planks, as has been described for pisé work; we have many castle and city walls so built, that have acquired

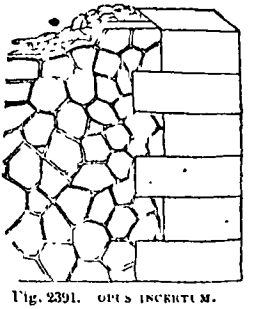


Fig. 2391. OPUS INCERTUM.

considerable hardness, and if occasionally bonded through with flat tiles, as at Richborough Castle, Kent, are difficult of demolition: such walls consist of three thicknesses, two forming the outer faces, and one the rubble core in the middle.

When the opus incertum is made with large polygonal facing stones, and piers of tile or brick are occasionally introduced, the effect is greatly improved, and the strength of the wall considerably increased; they are frequently met with in Italy, built with great care, and filled in with rubble composed of excellent mortar. This kind of masonry bears a strong resemblance to the cyclopean walls that are scattered over the country inhabited by the early Greeks; but the latter construction was executed with large blocks, and generally without mortar, its strength depending upon the locking of the several stones together, and the weight superimposed to keep them in their places.

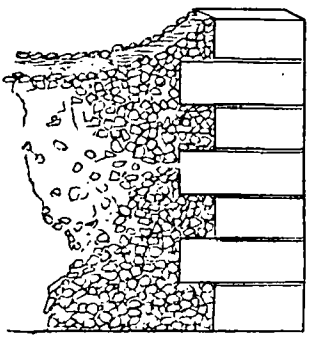


Fig. 2392 EMPLECTON.

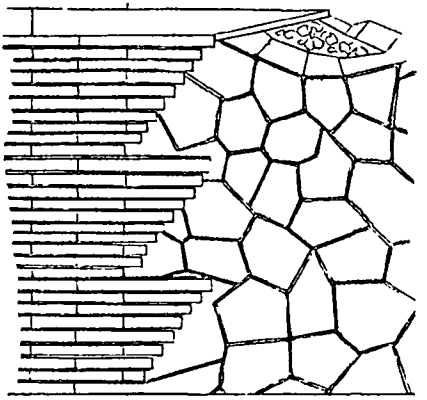


Fig. 2393. OPUS INCERTUM.

The Opus reticulatum is considered by Vitruvius the most beautiful species of construction; the term applied to it originated in its net-like arrangement, and we have an example in a part of the west front of Rochester Cathedral, supposed to have been built before

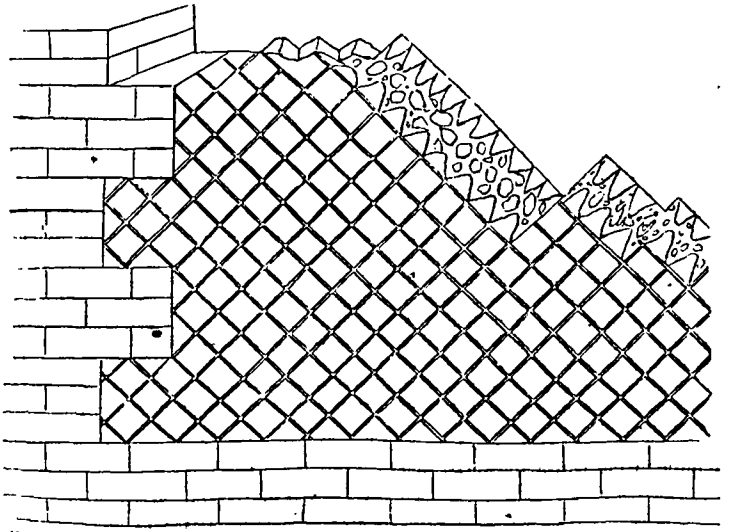


Fig. 2394. OPUS RETICULATUM WITH STONE.

the Norman Conquest: it is, however, liable to split, from the bed of the stones being unstable, and its deficiency in respect to bond; there are several varieties of this kind of work remaining in Italy, and some examples are attributed to the time of the Etruscans.

In Volscinium, the capital of the Volsci, are several remains: this style of masonry, found also at Tivoli, Præneste, Terracina, Fondi, Pompeii, &c., continued in use to the time of the emperors of Rome. It is generally formed of tufa, or small stones found in the neighbourhood of the constructions; the angles, as well as other portions of the wall, are carried up with tiles laid in regular courses; there are several varieties of opus reticulatum besides the two specimens given.

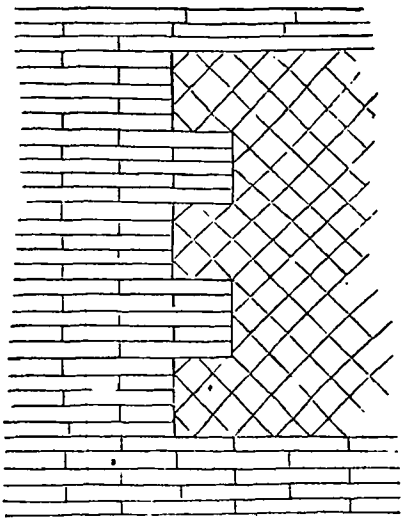


Fig. 2395. OPUS RETICULATUM WITH BRICK.

Walls formed with triangular tiles are found in the Coliseum and baths, &c., of the imperial city; other tiles of a square or oblong shape pass through the entire thickness, at every third or fourth course, and the interior is filled with rubble. In the ruins of Pompeii are walls built of tufa, rough stone, and brick, executed in a very careless and inefficient manner; sometimes only one course of brick alternates with one of stone, at others three courses of tile or brick intervene between one of tufa or squared stone.

Whatever may be the character of the masonry, one of the first considerations is the arrangement of the footings, which should be constructed of stones as large as can be obtained; they should all be squared, brought to an equal thickness in the same course, and laid upon their natural bed: the foundations should consist of several courses, each decreasing in breadth as they rise, in proportion to the thickness and height of the intended wall; this decrease of breadth should take place equally on both sides: ashlar facing backed with brick or rubble work is often substituted for brick and tile; but in those districts where stone is not easily obtained, there can be no better method than following the practice of the Romans.

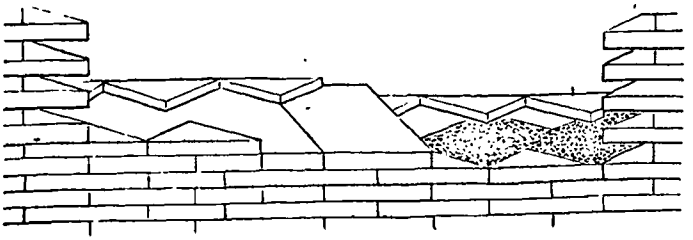


Fig. 2396. TRIANGULAR TILES.

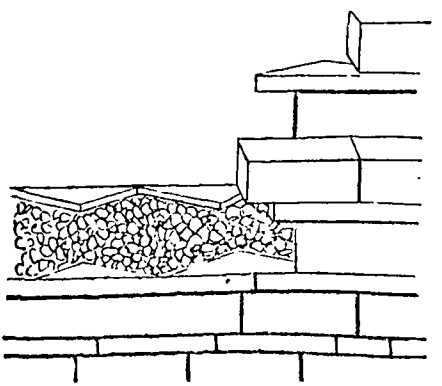


Fig. 2397. STONE AND TILES.

In some ancient walls the bond-stones pass through the entire thickness, and have a filling-in between the stretchers, composed of rubble or small stones bedded in mortar, the excellence of which has rendered them remarkably durable; such walls are classed under those called Pseudisodomon, from the courses varying in height.

Walls constructed partly of squared stone and rubble should have every second stone in the same course to run entirely through the whole wall, so that the work may be prevented from splitting in the direction of its width; the filling-in should be cautiously performed, and due regard paid to the shrinking of the mortar: the stone facing is sometimes rubbed

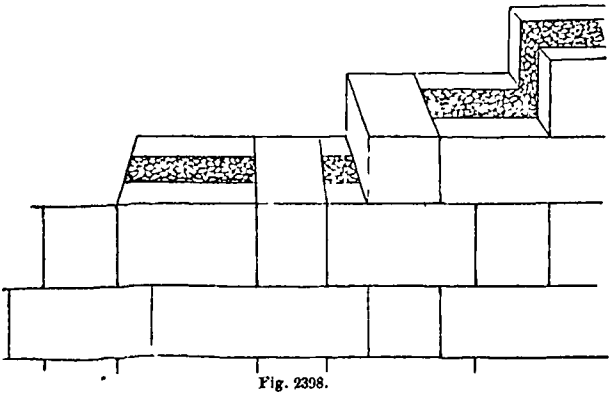


Fig. 2398.

perfectly smooth by means of a sand or grit-stone; at others it is either drove, broached, or striped; the former method is the least costly, is usually adopted, and generally known in London as *random-tooling* or *boasting*.

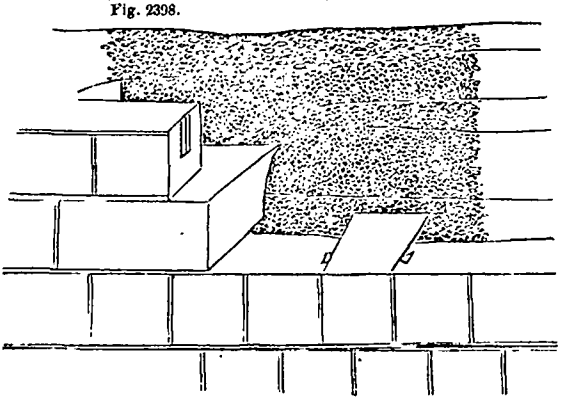


Fig. 2399.

The tomb of Cecilia Metella at Rome is cased on the outside with stone in courses, laid very regular, filled in behind with rubble work, which seems to have been done at the same time with the courses, as there are indications where the levels have been left and again commenced.

Wherever ashlar facing is adopted, the stones of each course should be placed on their natural bed, otherwise they will be liable to flush off at their joints; and where piers are required, unless they are of large dimensions, this kind of work must be abandoned; for there cannot be the requisite strength without the courses passing entirely through: in several churches constructed in the tenth and following centuries, we find the polygonal and cylindrical shafts of columns faced with ashlar, and hearted or filled in with rubble or chalk, run together with a durable mortar; where the latter has lost its tenacity, the columns have in several instances split asunder.

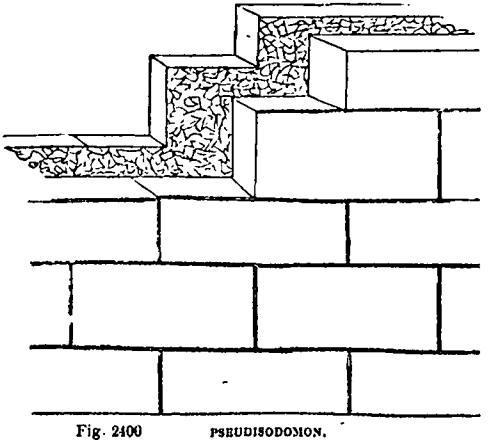


Fig. 2400 PSEUDISODOMON.

Pseudisodomum had the courses unequal in height: in other respects it resembled the isodomum. There are many remains of Roman walls where the stones of each course are of the same form as well as dimension throughout, ordinarily 3 feet long, 18 inches wide, and 9 inches in thickness; in some instances one course is laid flat, and the others are placed on their edges, so that the first reaches to the middle of the wall, which is filled in with rubble.

Diatonous was a term given by

the Greeks to that species of masonry in which the stones were of the same form and dimensions, but placed in courses of unequal height; such stones had their length equal to double their width.

At Athens there are several walls which have the courses of masonry of two different heights alternating with each other; the small course is only two-thirds that of the other; consequently three stones form the entire thickness in the one course, and two in the other or larger one, which doubly ties the entire thickness of the wall.

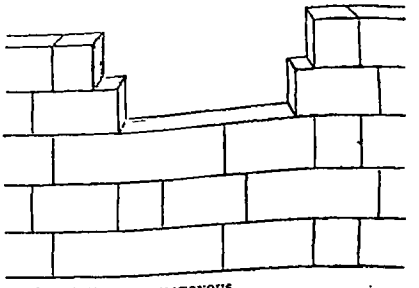


Fig. 2401. DIATONOUS.

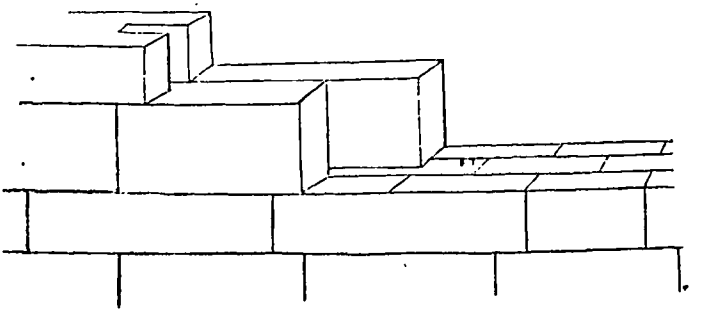


Fig. 2402. PSEUDISODOMON.

Another variety of masonry often met with in Italy bears some resemblance to those already described, but instead of presenting in the same course one header and one stretcher alternating, there is a course of headers and one of stretchers, like the old English bond in brickwork: as the headers pass entirely through the wall, the work is rendered very solid.

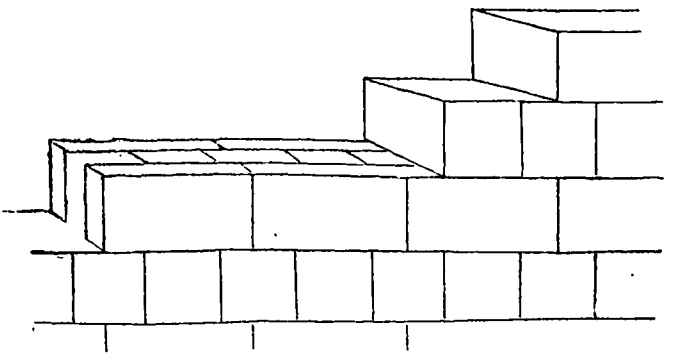


Fig. 2403.

Isodomum: the courses are all of equal height, producing both durability and solidity; first, because the stones are hard and solid, and therefore unable to absorb the moisture of the mortar, which is thus preserved to the longest period; and secondly, because the beds being smooth and level, the mortar does not escape, and the wall is bonded throughout the entire thickness.

To the admirers of solid construction we cannot do better than refer to the various methods employed in the amphitheatre of Vespasian at Rome: amidst the ruins of that stupendous pile, we yet observe specimens of almost every style of masonry, and a judicious application of stones of different degrees of hardness: brick and tile, with every kind of backing or filling in, was made use of where economy was desirable, or could be practised without sacrificing stability and strength; the large stones are wrought on all their faces, to suit their position around an oval plan, or circular on the elevation. The Coliseum is not only

a model for construction, but a school for the study of the mason's art; its general arrangement, and the proportion of its piers and walls, were no doubt most useful guides to the builders of the middle ages. There is scarcely a peculiarity in masons' work of which an example may not be found admirably effected amidst the corridors or vaultings of this edifice; and the test to which its stability has been subjected during nearly 2000 years is a convincing proof that every point in its construction was well considered, and must impress upon us the rather humiliating conviction that masonry has not progressed beyond the knowledge acquired by the ancients.

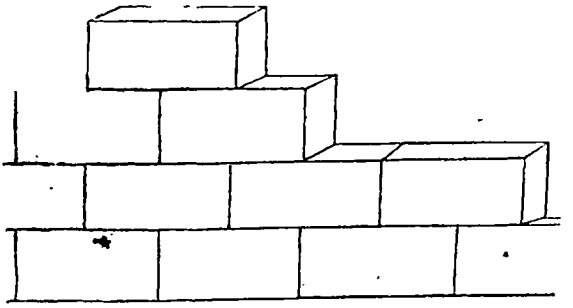


Fig. 2404. ISODOMON.

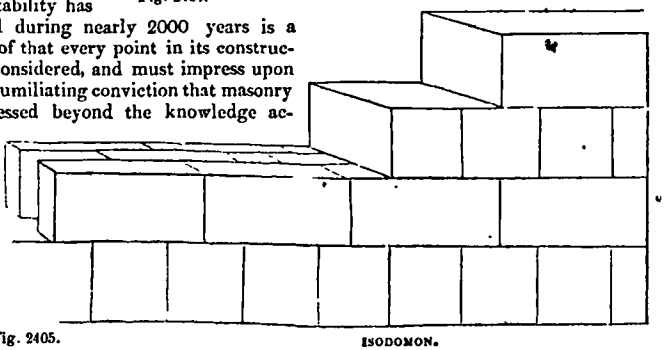


Fig. 2405. ISODOMON.

Cramps of metal, either iron or bronze, were much used by the ancients for uniting one stone with another, and were sometimes run with lead. The holes in the walls of the Coliseum and other monuments at Rome were drilled or cut for the purpose of extracting cramps of bronze that united the courses of masonry together: in the Parthenon at Athens the writer found oak dovetails applied for the same purpose. An excellent method of uniting a course of stone is by forming a triple range, notching one into the

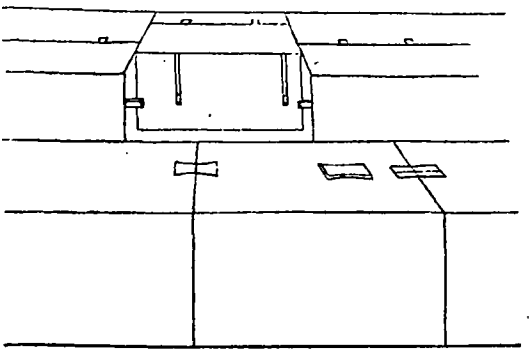


Fig. 2406.

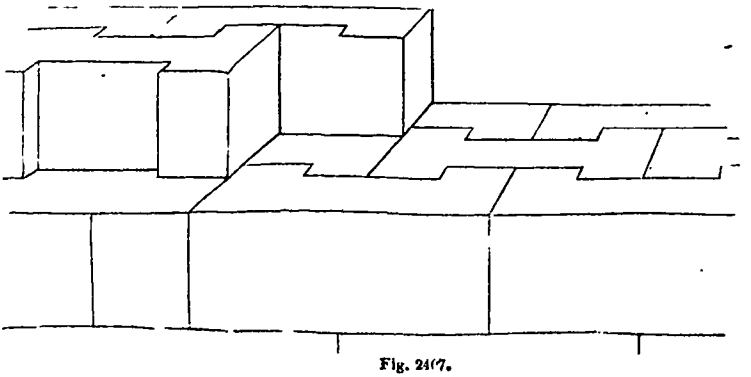


Fig. 2407.

other; this has in modern times been applied to circular walls, and found inefficient, on account of its cost and difficulty of execution, from the effects of unequal settlements in the building.

In the theatre of Marcellus at Rome the stones of the piers are prevented from sliding off their beds by sinking a portion of one into the other: the bed of each stone is divided into four parts by two right lines which cross in the centre at right angles, and abut against each other in the middle of their faces; the stones are placed upon each other, so that every one is united to two others, by means of the projecting parts of the upper stone, which keys into the sinking or mortise of the two lower, to which it is adapted.

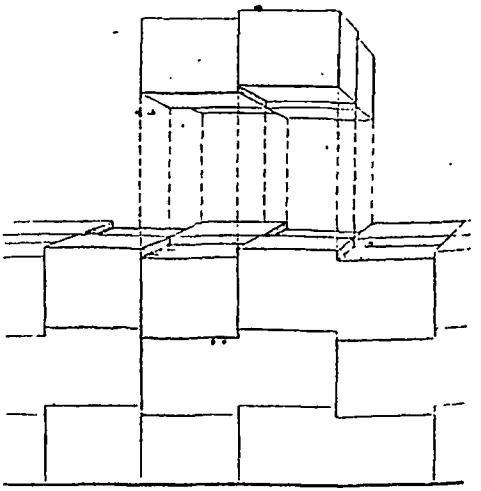


Fig. 2403.

Placing, and the Form to be given to wrought Stone, for Walls, Abutments, Piers, &c.—As every solid body has a tendency to descend in a vertical or perpendicular direction, it is evident that it can only be perfectly supported on a horizontal or level plan; thus the form best adapted to wrought stone, when applied to walls or piers, is that of a parallelepiped or perpendicular prism, or a solid placed on a horizontal plane, and terminated by vertical surfaces. The stones being laid on each other in union and level courses, the whole effort of the weight will fall on their base, and tend to consolidate them, so that the pressure of each stone on the other will increase their stability, and if the whole be well constructed, it will be almost as solid as if in one piece. As it is the effect of weight which unites the stones together, it is evident that the larger they are, the greater will be their stability, and the more solid their union; but their beds must be well dressed, and brought to a level, that they may have an equal bearing; for if of considerable dimensions they are more subject to break in parts where they have no bearing. The effect which causes the rupture produces also a general derangement of the construction, which renders it defective, certain points bearing a considerable weight, under which they break, whilst others are not in contact; the solidity and perfection of construction in wrought stone, which should be independent of any mortar or cement, consists in the stones being placed immediately over each other, so that they touch throughout their whole surface, both in their beds and joints, as was done by the ancients, and it is in the precision with which irregular constructions in large stones are executed, that their solidity depends, the joints being so well keyed, that their stability is often greater than that of squared stones. It must be observed that in construction of wrought squared stones the perpendicular joints do not add to the stability, whilst in those with irregular stones, being inclined in an opposite direction, the stability is increased by the manner in which the stones are keyed one into the other.

Of the Dimensions of Stones.—In many edifices, both ancient and modern, it has been observed that the stones used were too thin, viz. that they had not sufficient thickness in proportion to their length, and that in consequence they broke under the weight. These accidents arose from the stones not resting equally throughout the whole surface of their beds, either because these surfaces were not exactly dressed or levelled, or because some unequal settlement took place, which deranged the lower stones; the greater the thickness given to stones relative to their length, the greater is the power of resisting this effect, which it is often very difficult to foresee or prevent. For works which have very great weights to carry, such as walls and points of support, cubes are the strongest, but they have less stability, and do not form sufficient bond; those in which the length is much greater than the height have more bond, but less strength to carry the weight; according to the experiments made on stone, the length may be fixed at from twice to thrice their height, and their width from once to twice, supposing the stone of a moderate hardness. When stones are very hard, more than a foot thick, and wrought on all sides, their length may be from four to five times their height, and their width from two to three times; larger dimensions increase the expense without adding to the utility.

In ancient structures wrought stone was laid without mortar, or the small quantity used was so clear and fine that it only served to fill up the inequality of the bed, and did not prevent the parts between these inequalities from bearing on each other. The Romans observed that walls constructed of soft stone, or inferior brick, were subject to be affected by the changes of the atmosphere and driving rains; to obviate which Vitruvius advises that in apartments on the ground floor at a height of 3 feet from the pavement, the first coat of stucco be of potsherds instead of sand, and that a thin wall be built on the inside, leaving a cavity between for the air to circulate. Where there was not sufficient space for this second wall, tiles 2 feet square were placed, one over the other, in front of a flue left in the wall; G shows the position of the tiles up the face of the wall, D its effect when plastered over or stuccoed: A is a channel or drain, contrived to receive any moisture that may run down the flue, or hollow part of the wall.

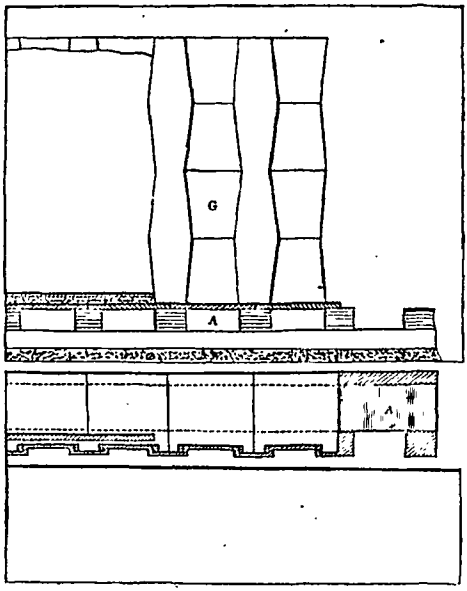


Fig. 2409. PLAN OF WALL.

For cottages the same arrangement might be adopted with great economy, and in several parts of England walls are constructed in a somewhat similar manner, by setting the bricks on edge, both on the inner and outer face, so that in a 9-inch wall, there is a space of 4 inches between them. To produce the requisite strength, each header passes through the entire wall, and by carefully excluding the mortar or dust from occupying the vacuum between the two faces of the brick, a dry wall is secured, and a much less quantity of material consumed than is required for a solid 9-inch wall. Stone walls might be so constructed, and it has been suggested to work within thin walls vertical plates of sheet iron, pitched previously to insertion, to keep out moisture.

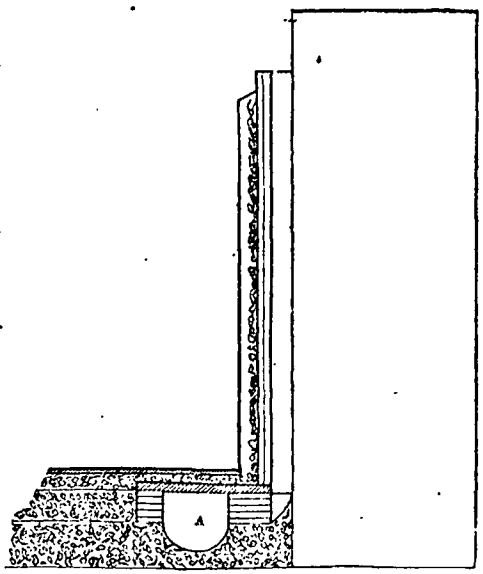


Fig. 2410. ELEVATION OF WALL.

The Romans formed the floors of their rooms very carefully; after excavating the earth to the depth of 2 feet, they well rammed the bottom, and laid over it a layer of broken stone or potsherd prepared for the purpose; on this was spread a composition of pounded charcoal, lime, sand and ashes, 6 inches in thickness, which was rendered perfectly smooth by first rubbing it with stone and then polishing it. Rakes, rollers, scrapers, and trowels, were made use of during the processes, and several of these floors remain at Pompeii, which attest their strength and durability.

It was the practice of the Romans to construct the upper portion of their walls with testaceous materials, forming a projecting cornice to carry off the water. When mouldings

are made in cement or plaster, for the sake of economy, they are run either upon projections of rough stone or tile; the tools required are trowels of different forms, and chisels and hammers to cut away the masses which may obstruct the working of the running mould, which is cut out to the form intended, and passed along the face of the cement, spread over the cornice.

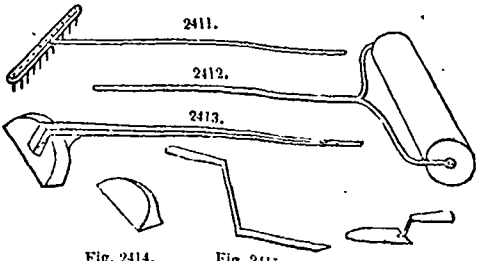


Fig. 2414. Fig. 2415. Fig. 2416.

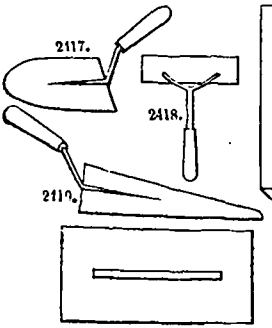


Fig. 2420.

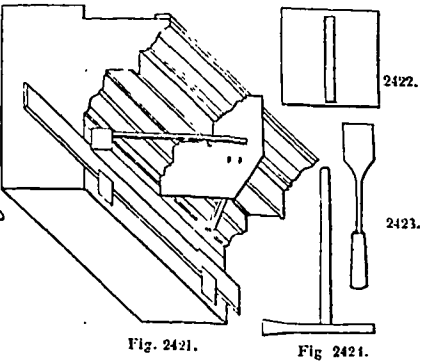


Fig. 2421. Fig. 2421.

Stone Pipes are in many parts of the continent made use of for conducting water, and are sometimes laid in the thickness of the walls, to bring down that which falls upon the roofs: they are bored by simple means, setting the block of stone upright, and in the centre of the intended pipe or cylinder placing a wooden plug having a hole through which the axis of the spindle passes; the cutter is attached to this, and rotary motion is obtained by means of a pulley; the action of this borer is that of the common drill.

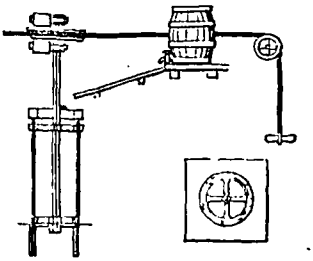


Fig. 2425. BORING STONE PIPES.

Arches composed of four voussoirs cannot sustain themselves, whatever be the resistance of the piers, if their thickness be less than the seventeenth part of their span; but they sustain themselves with a less thickness when the arch is extradossed equally over $\frac{1}{3}$ of its extent, the surplus being comprised in the piers, as shown in fig. 2427.: when the thickness of the arch is increased, it may be made only $\frac{1}{30}$ part of the span.

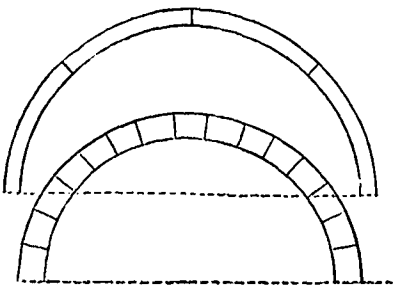


Fig. 2426.

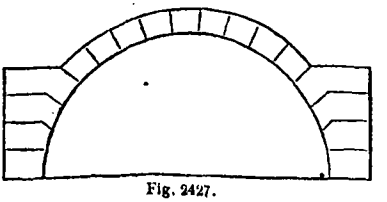


Fig. 2427.

Arches of Equilibrium, being calculated to stand by themselves, must necessarily be better

adapted to sustain any additional weight, which will be opposed by the whole resistance of the cohesion of their parts; but where the arch does not equilibrate, a portion of the cohesion is employed in resisting the inequality in the actions of its own parts. "Equilibration," observes Mr. Samuel Ware, in his very admirable treatise on the properties of arches and their abutment piers, "is as important as the construction of the arch." All arches which support themselves, whatever their form, include a catenarian curve in their thickness, upon the principle of a line formed of a perfectly flexible chain, suspended at its two extremities, which is an arch of equipollence.

In semicircular arches all the joints prolonged intersect at the centre; consequently if a horizontal line be drawn at such a distance from the centre that the parts comprised between the joints of the key are equal to the thickness to be given to the arch at the centre of the key, the other parts of this line, intercepted by the joints, will express the differences of the tangents, and the thicknesses to be given to each correspondent voussoir. To

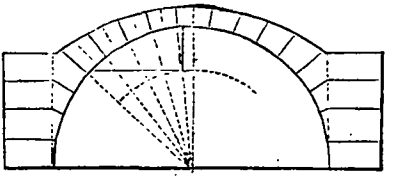


Fig. 2428.

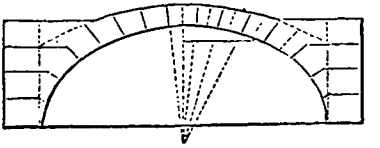


Fig. 2429.

determine the point where the horizontal line should be drawn, draw a parallel to the axis, at a distance equal to half the thickness of the centre of the key of the arch, which will cut the joint of the key prolonged in a point, and is that required. By measuring the

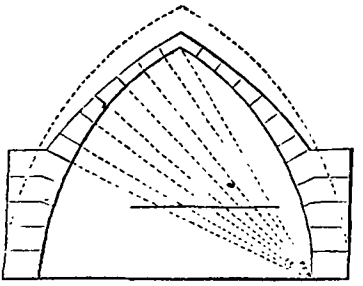


Fig. 2430. POINTED.

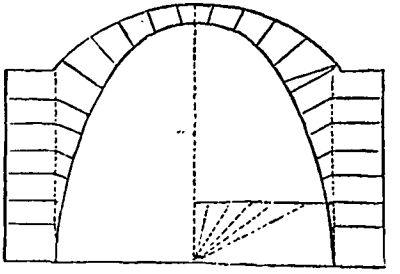


Fig. 2431.

widths on the straight line, we have the thickness to be given to each of the voussoirs comprised by the two radiating lines; and when the thickness of the keystone is determined, we must set out half this depth on the intrados from the axis of the arch, drop a per-

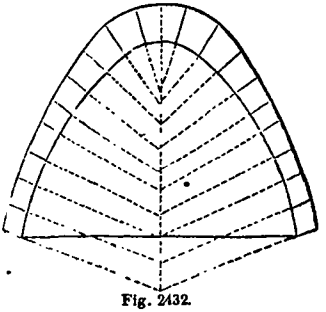


Fig. 2432.

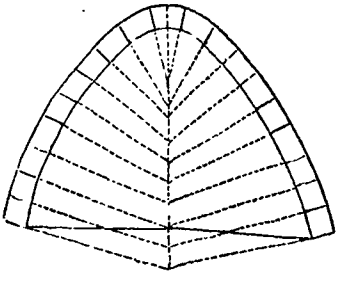


Fig. 2433.

pendicular from that point, and when it cuts the radiating line that represents the side of the keystone, draw a horizontal line, as shown in the various figures, upon which we obtain the depths to be given to the respective voussoirs comprised between the lines: by this means the extrados of every kind of arch, parabolic, hyperbolic, or elliptical, can be traced.

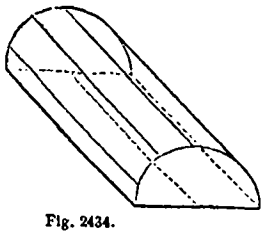


Fig. 2434.

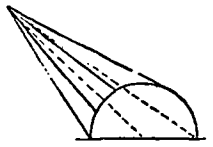


Fig. 2435.

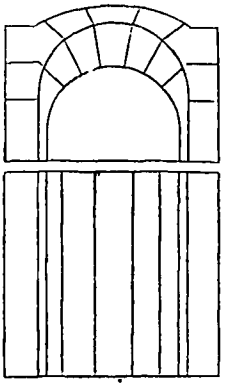


Fig. 2436. CYLINDRICAL VAULT.

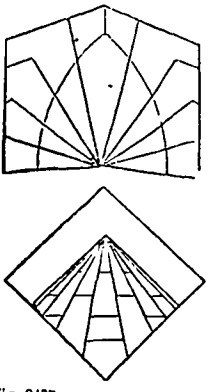


Fig. 2437. CONICAL VAULT.

Cylindrical Vaults have their voussoirs always parallel to their axis, whatever their curvature or situation: oblique or inclined vaults of this description should have their courses of voussoirs similarly arranged.

Conical Vaults have their courses inclined towards the point of the cone, whether they form a part of an entire, or the frustum of a cone; taking care in the former case to avoid the too great acuteness of the voussoirs by making the point or *trompillon* of a single stone. When the conical vault is of a size which renders the lower voussoirs too thin, its length must be divided into several parts; so that if the great circle be divided into 8 voussoirs, and the length of the arch into 4 parts, the second part should be divided into 5 voussoirs, the third into 3, and the fourth be constructed of a single piece: these slices must be comprised between surfaces perpendicular with that of the cone, by cutting off any irregularity in the first row.

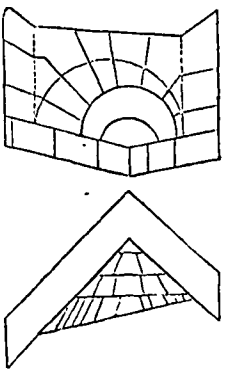


Fig. 2438. OBLIQUE CONICAL VAULT.

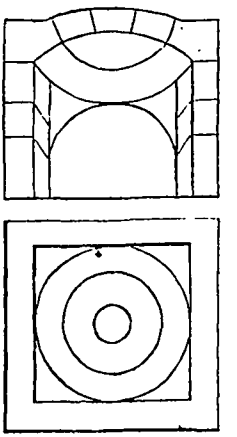


Fig. 2439. SPHEROIDAL VAULT.

Spherical Vaults consist of horizontal courses of concentric rings placed upon each other: when the rows of voussoirs form squares on the plan, or other plane figures, as triangles, pentagons, &c., they are difficult of construction and not so solid, especially at the angles of the polygons; nor does this arrangement effect so firm a tie as when the voussoirs are arranged in horizontal rows.

When the vaults are composed of several parts the rows of voussoirs should be disposed as they would be in the vaults originating them; thus in the figures composed of parts of cylindrical vaults uniting in the centre, the rows of voussoirs are parallel to those axes.

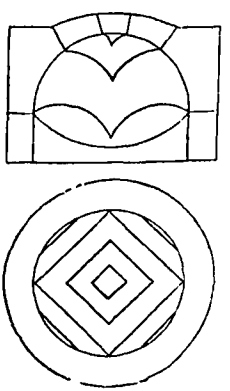


Fig. 2440.

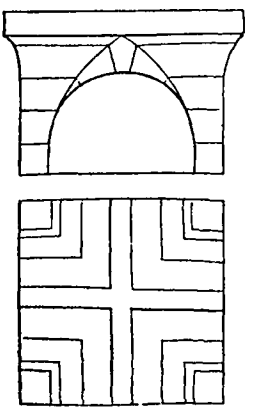


Fig. 2441.

Diagonals drawn from one angle of the hexagon to the other, and passing through the centre, form salient angles in the *voute d'arète*, and re-entering angles in the *voute de cloitre*.

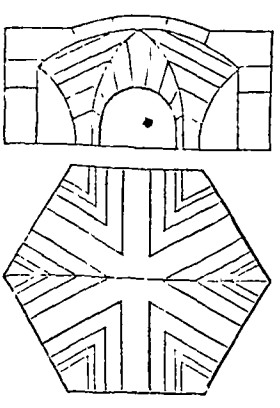


Fig. 2442. VOUTE D'ARETE.

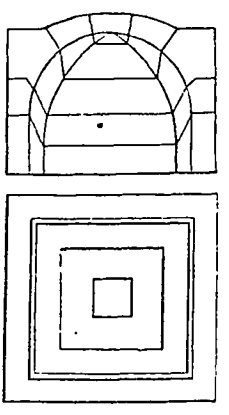


Fig. 2443. ARC DE CLOITRE.

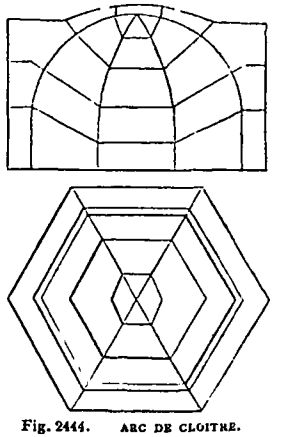


Fig. 2444. ARC DE CLOITRE.

In the Voute d'arète, composed of triangular voussoirs, these parts have no other supports than the angles of their plan: whilst in the vaults termed *arc de cloitre* they are supported on their side, which is carried on the wall throughout its whole length: hence the latter are much more solid, and have less pressure than the *voute d'arète*.

Flat Arches are constructed by making each course of voussoirs run parallel with the faces of the walls which support them.

In all arches stability being the object, cohesion and friction are necessary: the larger the voussoirs, or, in other words, the fewer the joints introduced, the less liability there is to derangement, as the cohesion is increased: but we must always regard the nature of the material employed, and its disposition to fracture. The mason as well as the bricklayer should avoid the impropriety of making his *skew backs* to flat arches too great; for an arch composed of stones with parallel beds and slightly inclined joints cannot yield until some one of them slides out, or becomes crushed. At page 410. (fig. 410.) is shown a flat arch at Coningsburg Castle, where the voussoirs are held up by an indented joint: similar arches are found among the buildings of the Romans, over the great western door of the cathedral at Rochester, and elsewhere.

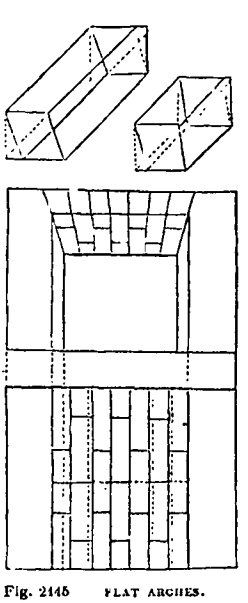


Fig. 2445 FLAT ARCHES.

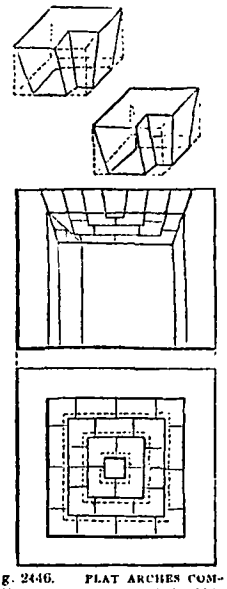


Fig. 2446. FLAT ARCHES COMPRISED BETWEEN FOUR WALLS.

Flat Vaults over a square plan are comprised between four walls which support them: the rows of voussoirs form concentric squares; those of the angles are common to two of the sides; the key is square, and locks the whole together. The lines traced on the plan show the position of each stone; the dark line is the lower joint, and the lighter line the upper. Vaults of such a description are rarely to be met with in England, and require great skill for their execution: wherever they are introduced, an iron tie or a strong abutment is requisite to prevent the yielding which takes place at the joints of the stone.

A flat Vault on a circular plan has its voussoirs arranged concentrically, and locked by a conical key.

Flat Vaults supported upon four pillars require a different arrangement; the rows of voussoirs are parallel to the

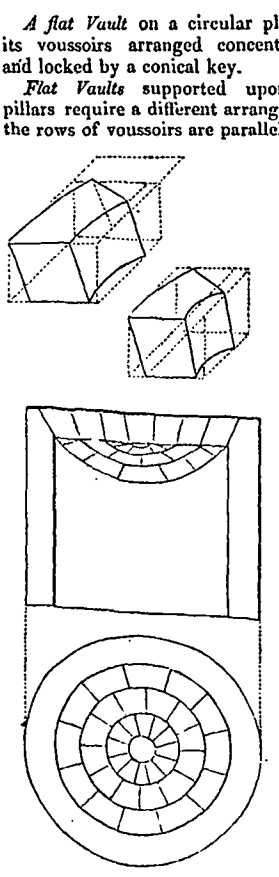


Fig. 2447. FLAT VAULT ON A CIRCULAR PLAN.

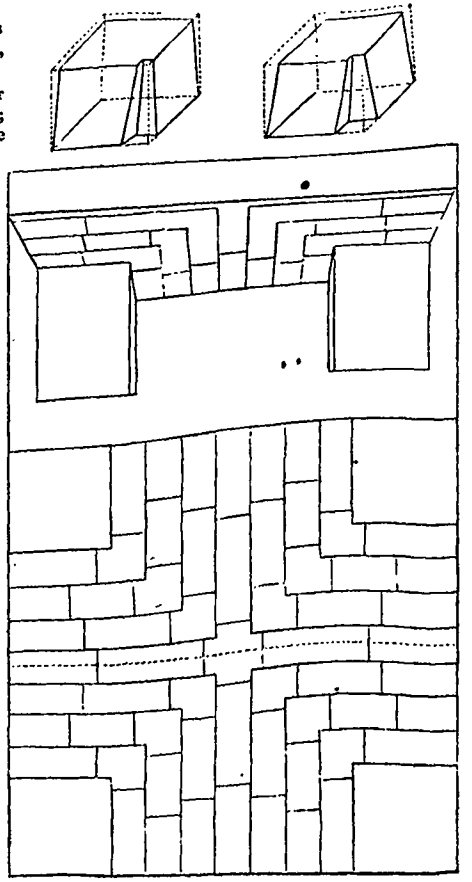


Fig. 2448. FLAT VAULTS SUPPORTED ON FOUR PIERS.

inner faces, and intersect at right angles on the diagonals, on which are placed voussoirs common to the two sides: the last row on each side is cut to receive the diagonal voussoirs.

To trace the Caissoons in spherical and spheroidal Vaults is the most difficult portion of a mason's work: after the circumference of the dome is divided into the number of intended caissoons, from the centre of each perpendiculars are raised, united in the key of the dome; these lines may be considered as the circumferences of several vertical semicircles which intersect at the axis of the vault: whence it results, that if a cord be stretched, to represent the diameter of one of these circles, the points of the circumference will be found by elevating with a plumb-line several corresponding points on the surface of the vault, a line passed through which will be the circumference of the circle. To draw them, a template or mould cut to the curvature of the vault is employed, which should not be more than 3 feet in length. The points raised upon the diameter represented by the cord should be not less than 18 inches apart, so as to have always three points to fix the mould: instead of raising these points perpendicular to each diameter, we may effect this in a far more expeditious and simple manner, by means of a plumb-line suspended from the centre of the key; if at night, a light may be placed at each division opposite to that successively, through which a vertical circle is to be drawn, which will be indicated in its whole extent by the shadow of the thread of the plumb-line, serving to place the wooden mould as before described. After having thus drawn the centre of the caissoons, their height may be thus determined: circles are inscribed, one above each other in the divisions or parts of the development, comprised between the vertical arcs which pass through the middle of the sides, as is shown in the figure B. In order that the first row of caissoons may experience less foreshortening, the first may be raised above the

springing, as at C. To determine the lower circle of the first row, a semicircle is first described, through which the summit of a spherical triangle is traced; having then divided the angle formed by this circle, we must proceed as shown in the figure, drawing the spherical angles upon each caissoon, which is a tedious process. For octagonal and lozenge-

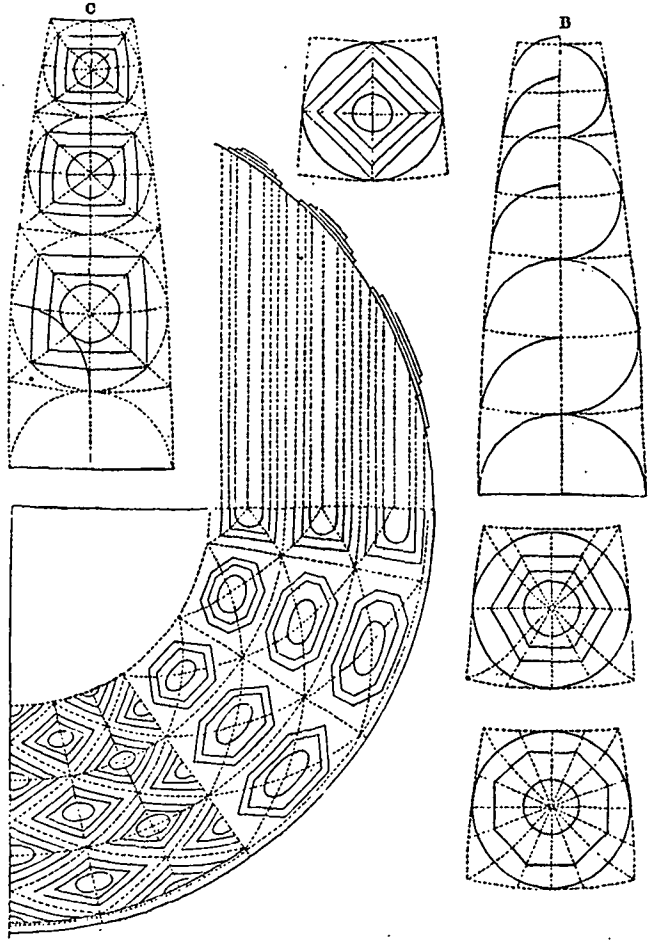


Fig. 2449. CAISSOONS IN SPHERICAL VAULTS. Fig. 2450.

shaped coffers a similar system must be adopted, taking care to project the several lines upon the spherical diagonals.

In setting out the caissoons of a dome, like that of the Pantheon at Rome, after having decided the number, we must commence with the plan, and set out the lower tiers, with all their sinkings and ribs between: perpendicular lines drawn up from these divisions to the base line of the elevation of the dome will determine the commencement of the several curved lines that are to bound the caissoons in their vertical position: to mark out their direction, an inner circle, of the diameter of the dome, must be drawn on the plan, at the height of the first caissoon, divided in a similar manner, and then the perpendicular lines be proceeded with as before.

Domes that are elliptical on their plan must, in order that the caissoons may not produce a disagreeable effect, have their rows comprised between horizontal ellipses similar to that of the base. The projection of the sides should also form right lines meeting at the centre; these lines, which vary in length, are the great axes of vertical semi-ellipses, which give different measure, and curves to the developed width of each row of caissoons, and even for the upright edges of each.

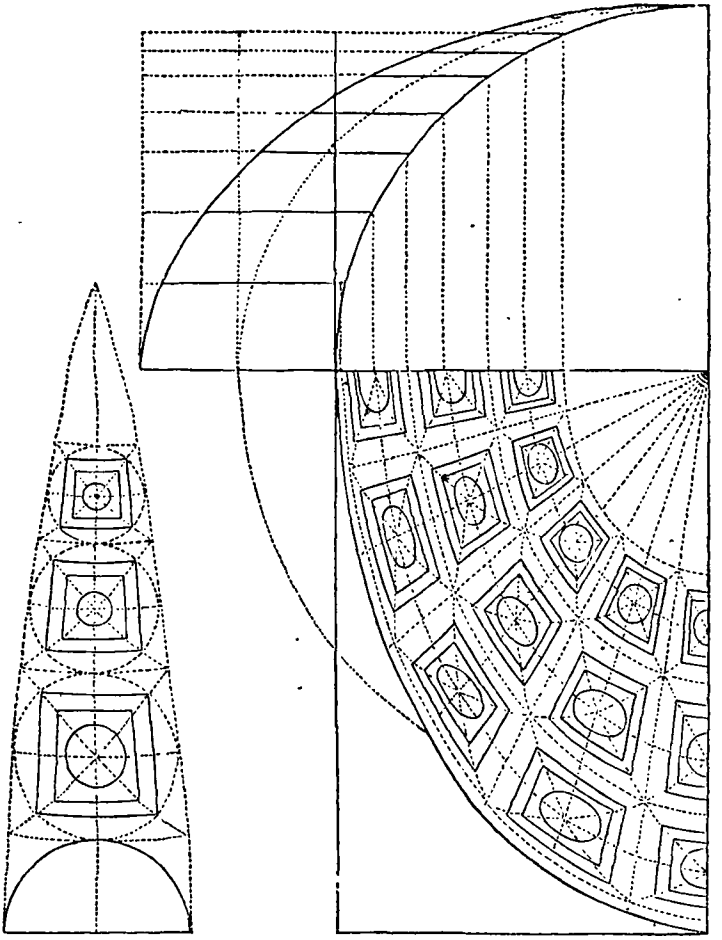


Fig. 2451. OVAL. Fig. 2452.

To trace the Stones forming an Arch with parallel Faces. — Fig. 2453. is the elevation of the arch, showing the forms of the voussoirs, under which is the plan of the arch

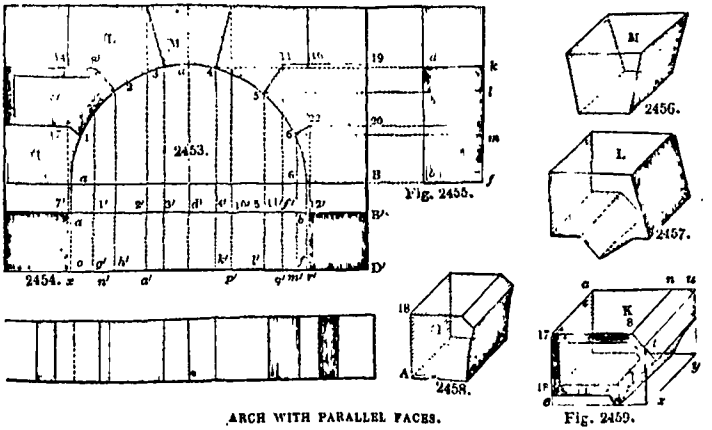


Fig. 2455.

ARCH WITH PARALLEL FACES. Fig. 2459.

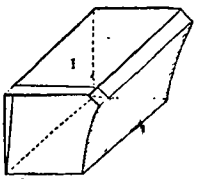


Fig. 2460.

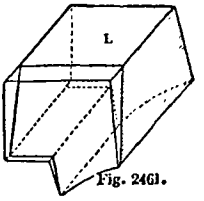
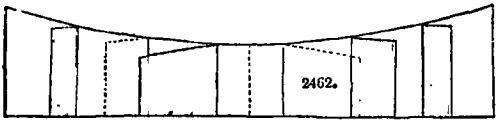


Fig. 2461.



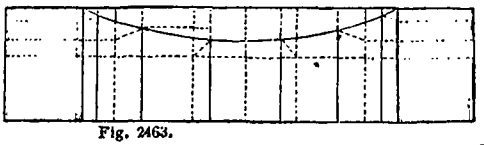


Fig. 2463.

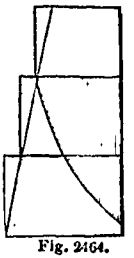


Fig. 2464.

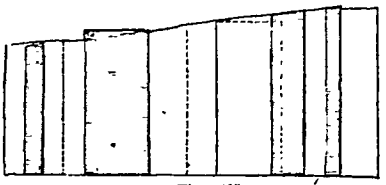
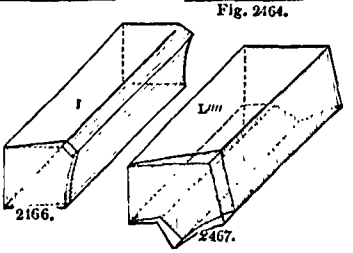


Fig. 2465.



2466. 2467.

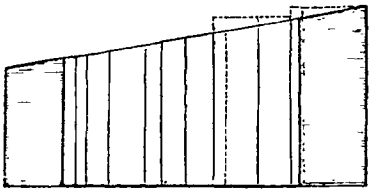


Fig 2468.

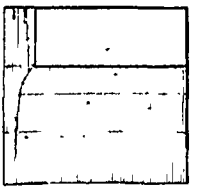


Fig. 2469.

reversed; the lines indicate the joints of the soffite, and those dotted the projection of the interior section; these are formed by means of the profile, on which is taken, according to the vertical or perpendicular face, the thickness corresponding to each joint of the soffite, thus: fig. 2455. shows the section and its corresponding lines. A mould must first be formed for each of the voussoirs, I, K, L, M, for the purpose of accurately tracing them; one is shown in fig. 2459. marked K, and in the voussoirs drawn in perspective. The manner of working it is thus performed (fig. 2459.): the upper bed is first cut, and the two parallel lines 17 t and an are to be drawn, at a distance corresponding to the thickness to be given to the arch; then the two faces, 17 tex, and auy, at right angles

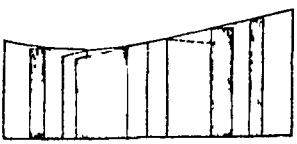
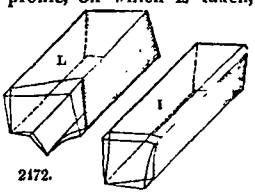


Fig. 2470.



2472. Fig. 2473.

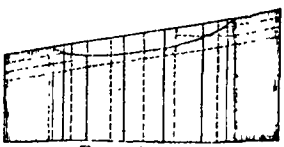


Fig. 2471.

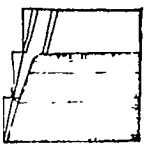


Fig. 2474.

or square with the bed first obtained. When the perpendicular faces are formed apply the mould, and trace out the figure to be given to the voussoirs; the stone is then reduced by cutting away all extending beyond the outline of the mould, and between the dotted lines. For oblique and circular arches the stones may be traced in a similar manner; their developement and profile are shown by the figs. from 2462. to 2474. By observing the letters on each there will be no difficulty in applying the several stones to their respective positions.

The Development of Arches, either perpendicular, oblique, or circular, on the Plan.— A B C D is a half cylinder, on which are placed arches extradossed, of an equal thickness, and to which it acts as a newel. Fig. 2475. represents them geometrically; fig. 2476. the profile, and in fig. 2477. the whole is shown in perspective at an angle of 45°. The development of these several arches is expressed in figs 2478, 2479, 2480, and 2481.; the voussoirs are shown lying on their extrados, so that the joints appear open at their intrados, where they form angles that separate their soffites. The development of the straight arch E F is shown by fig. 2478.; that composed of two parts forming an angle G H I, by fig. 2479.; the circular L M N by fig. 2480.; and that which is circular on the plan O P Q, but situated obliquely with regard to the axis of the cylinder, by fig. 2481. To set out these developments, take from the profile (fig. 2476.) the width of the faces of the extrados, which carry on a right line *df*, supposed perpendicular to the axis in *d*, 7, 8, 9, 10, 11, 12, and *f*. For the straight arch E F, it will be sufficient to draw a parallel at *df*, at a distance equal to the thickness of this arch: having then divided each face of the extrados into two equal parts, carry on each side half the width of the internal face, and as it is narrower than that of the extrados, the lines drawn by the points *a*, 1, 2, 2, 3, 3, 4, 4, 5, 5, 6, 6, 6, and *b*, will leave on each side spaces which will represent the joints foreshortened, as shown by fig. 2478.

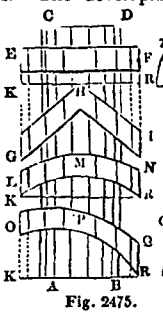
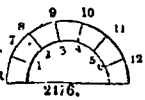


Fig. 2475.



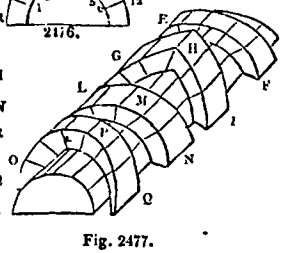


Fig. 2477.

For the other arches, G H I, L M N, O P Q, the faces of which are oblique or circular, it will be necessary on the horizontal projection, fig. 2475. to draw the lines K R, perpendicular to the axis, which may pass at pleasure through one of the projecting extremities, as the point H for the arch G H I, M, for L M N, and R, for O P Q.

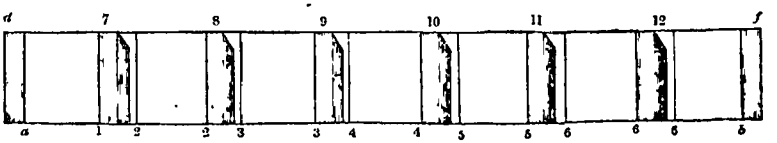


Fig. 2478.

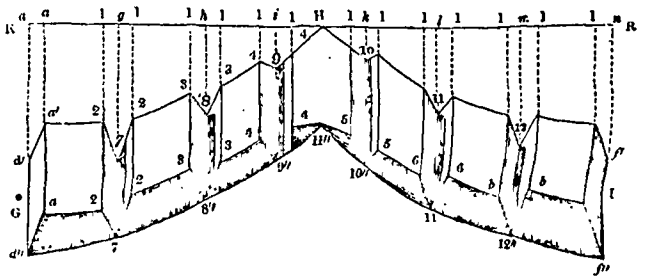


Fig. 2479.

Then prolong the lines from the points of the extrados and intrados until they meet the directing line K R: for the arch G H I, for example, make the development for the faces of the extrados, by carrying, as already stated, their width taken on fig. 2475., on the line developed, *a n*, fig. 2479., from *a* through *g*, *h*, *i*, *k*, *l*, *m*, and *n*; having drawn indefinite perpendiculars through all these points, carry on each the distance of their extremities to the directing line K R on fig. 2475.; then carry the distances *c d*, *g* 7, *h* 8, *i* 9, *k* 10, *l* 11, *m* 12,

and nf', through ad, $g7$, $h8$, $i9$, $k10$, $l11$, $m12$, and nf', on the development, fig. 2479.: then apply the thicknesses $d'd''$, 77, 88, &c. &c., to the development fig. 2479 from d' through d'', from 7 through 7, from 8 through 8, &c. &c., and tracing through these points the curves d', H', f', and d'', H'', and f'', we shall have the faces of the extrados.

For those of the intrados, take on the profile fig. 2475. half the difference of the internal and external faces, which will be found by making two parallels to the lines, which pass through the middle of each voussoir, as $3r$ and $4s$, with relation to the key.

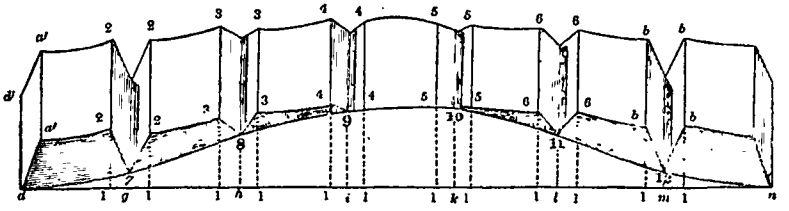


Fig. 2480.

The arch in question being extradossed in equal thickness, the differences $9r$ and $s10$ are throughout the same, and rs always gives the width of the inferior face: thus to have the position of the latter, draw $9r$ through $s10$, on the line dn of the development, fig. 2479. through a,a, $1g$, $g1$, $1h$, &c. &c., and after having drawn by the points a, and all the points

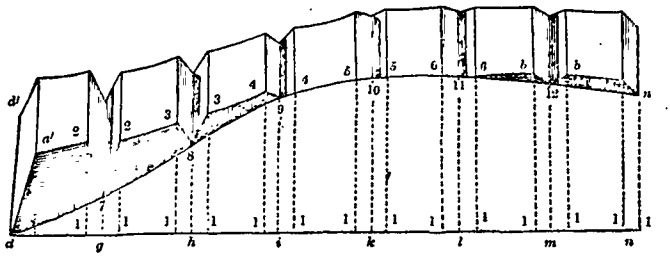


Fig. 2481.

1, indefinite parallels, carry on each the width of the corresponding lines traced on the cylinder, that is to say, au, 11, 22, 33, &c. &c., of the fig. 2475., through a,a,a', 1,2,1, 3,1,4, &c., fig. 2479.

As the lines which terminate each of these faces are in this direction curved, it will be necessary, for greater precision, to take for each a measure in the centre of the face, which will give the curve of the opposite sides, by carrying throughout an equal distance dd

To bring together these two faces, and to give them the appearance of reversed voussoirs, draw the lines $a1$, d, ad'', 2,7; 7,2; 3,8; 8,3; 4,9; 9,4; which will represent the joints foreshortened: the developments of the two other arches, fig. 2480. and 2481. L M N, and O P Q, may be found in a similar manner, the same numbers and letters being used for the developments of each.

For Skew Arches, inclined in walls circular on the plan. Fig. 2482. is the elevation;

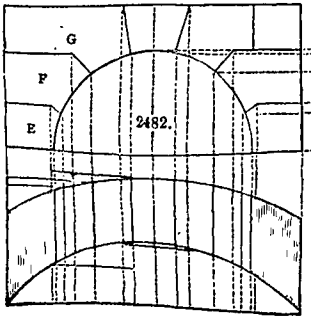


Fig. 2483.

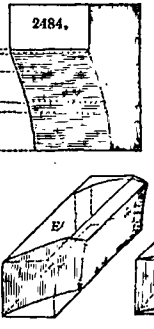


Fig. 2486.

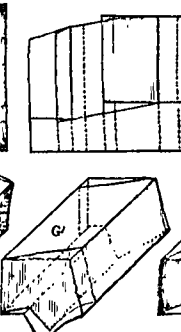


Fig. 2487.

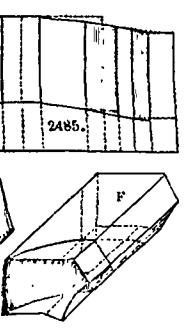


Fig. 2488.

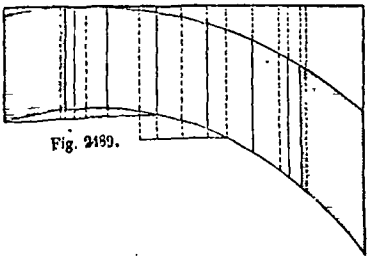


Fig. 2489.

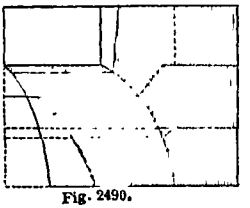


Fig. 2490.

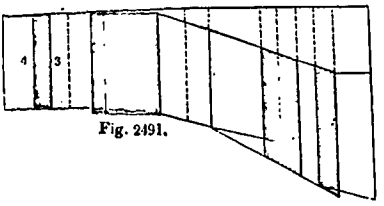
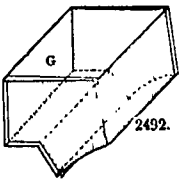
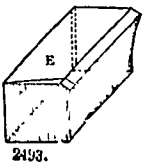


Fig. 2491.



2492.



2493.

fig. 2483. the plan of the same; fig. 2484. is the profile or section, and fig. 2485. its development; fig. 2489. is the plan of an arch where the faces are not parallel; fig. 2490. is the profile, and fig. 2491. the development; fig. 2494. is a skew arch, with the wall battering; fig. 2496. its profile, and fig. 2498. its development. The voussoirs fig. 2486., 2488., and 2487., shown in perspective, belong to the arch, the plan of which is at fig. 2483.: the voussoirs fig. 2493., 2492., show those of the arch fig. 2489., and 2495., 2497., those of the inclined arch fig. 2489.: these voussoirs need no further description than that they are to be cut first, as if for arches in walls, with their faces perpendicular, and then by the means of the mould the projecting parts to be cut off are determined, for the purpose of forming the curve of the respective faces: to prevent the voussoirs from sliding on their joints the ancient masons used holes and notches; in others mortises and tenons, which fitted into each other, an example of which is seen in the Coliseum.

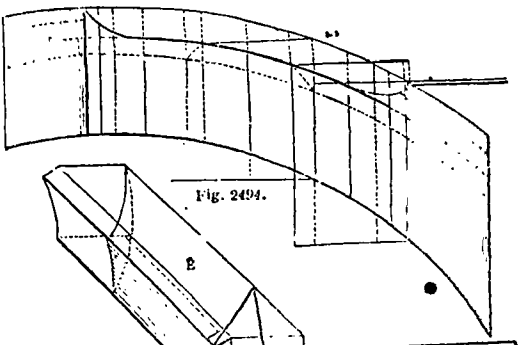
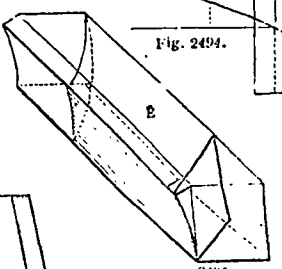


Fig. 2494.



2495.

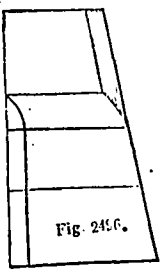


Fig. 2496.

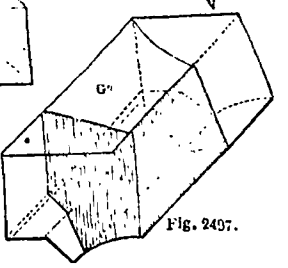


Fig. 2497.

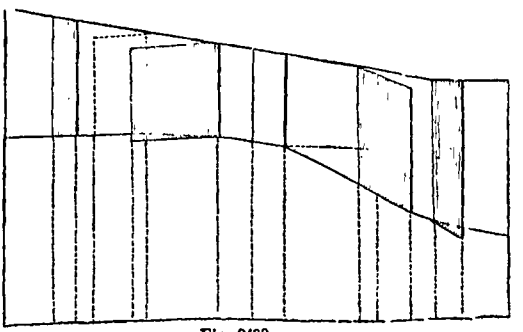
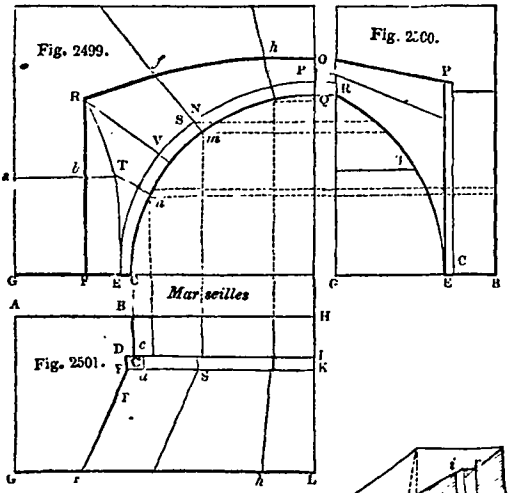
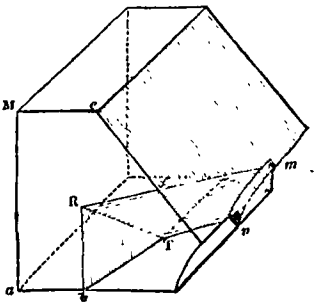
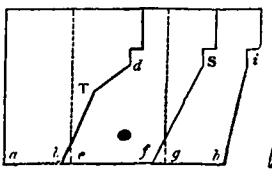


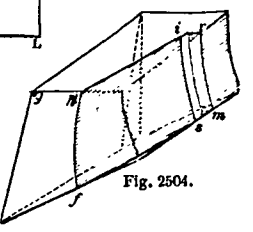
Fig. 2498.

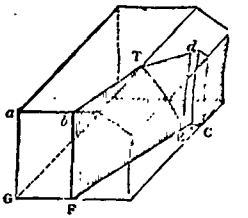
To facilitate the opening of a door or casement inwards, the arch is constructed in the manner shown in the accompanying diagram: in France this method was first practised at Marseilles; these voussoirs or vault headings are formed by right lines intersecting three arcs of circles: the first is shown on the plan at E K, in the elevation at E S P, and on the profile or section at P E; the second is the arc R T E, and the third the arc R O: from the point R on the elevation draw the line R V, perpendicular to the arch E S P;

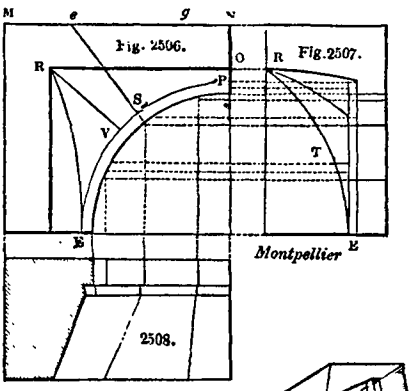


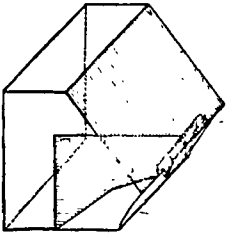


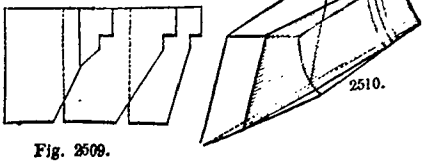


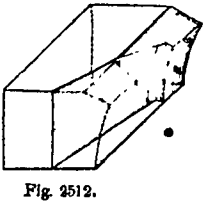












the right lines, which form the upper part of the vault, are to be drawn from the arc R O to the arc S P, and that of the lower part from the arc E V to the arc R T E. To determine the position of these lines, divide R O and V P into the same number of equal parts, and draw them from one point of division to the other, and do the same on the arcs R T E and E V.

The plan, elevation, and section are more fully comprehended by the development of the first, second, and third stones, in isometrical perspective; the mould by which they are set out is also shown: the letters sufficiently indicate their position, as the corresponding parts are similarly lettered in the plan, elevation, section, voussoirs, and mould by which they are cut. Another method practised at Montpellier shows a difference at the head, which instead of being circular is straight.

Clement Metezeau adopted this arch to decorate the internal face of the gate of St. Antoine, at Paris: it has a semicircle at the back, and resembles a portion of an hemispherical niche; the springing of the head, being from a straight lintel, is gathered over very ingeniously to meet the curved line which bounds the recess. Divide the circle F O and the right line I H into equal parts, observing that the latter must contain two divisions less than the circle; the entire semicircle would contain seven, and the horizontal line five.

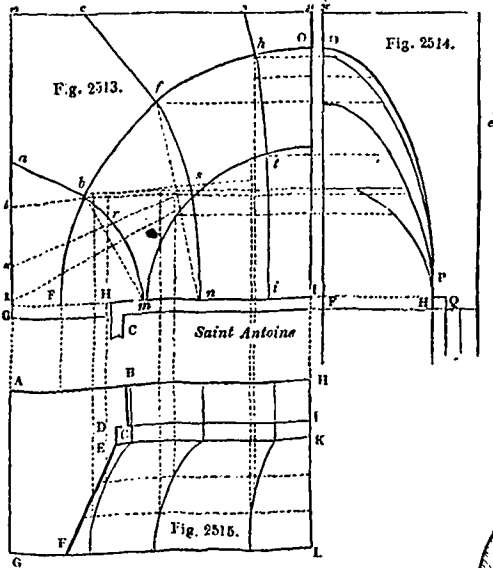


Fig. 2513.

Fig. 2514.

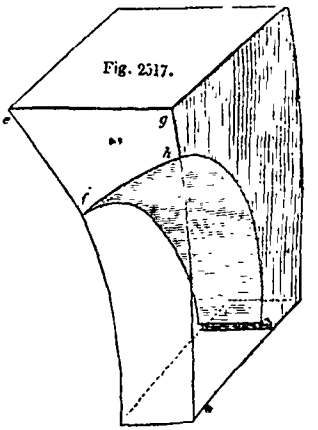


Fig. 2517.

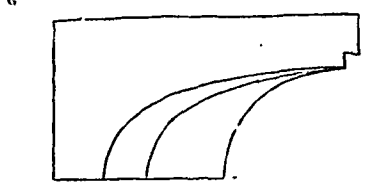


Fig. 2516.

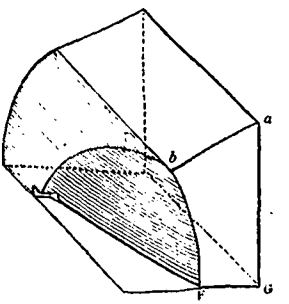


Fig. 2518.

To find the centres of the curvatures of the joints, draw the right lines *hi*, *fn*, *bm*; from their centres raise perpendiculars, as 1, 2, and 3; where they intersect I H prolonged will be the centres required.

The curvature in this vault is represented by a quarter ellipsis, whose two semi-axes are F O and F H; they may be drawn by means of ordinates to a quarter of a circle of which F H will be the radius; or by means of foci or points, which is the most simple. Having developed the arcs *hti*, *fsn*, *brm*, they are taken for the great axis of quarter ellipses, which indicate its curvature, and then drawn on a flexible mould.

In cutting the stone commence with the face *nf*, *fh*, *hi*, and *in*. The voussoirs in isometrical perspective show the two intermediate stones defined by the corresponding letters.

Intersecting semicircular Vaults. — Where one semicircular arch intersects another, a void or opening is formed, its figure varying with the angle of intersection, and the diameter of

the vault: in the accompanying diagram a semicircular vault is penetrated at right angles by one of a less diameter. A H B is the form of the void or opening determined by the intersection of perpendiculars dropped from the joints of both the arches. The development of the soffite or intrados of the lesser arch is of that portion of the arch comprised between the right line pq on the plan, and the curved line A H B forming the arris of the void or opening: the upper stone, in isometrical perspective, shows the key of the arch

Fig. 2519.

Fig. 2520.

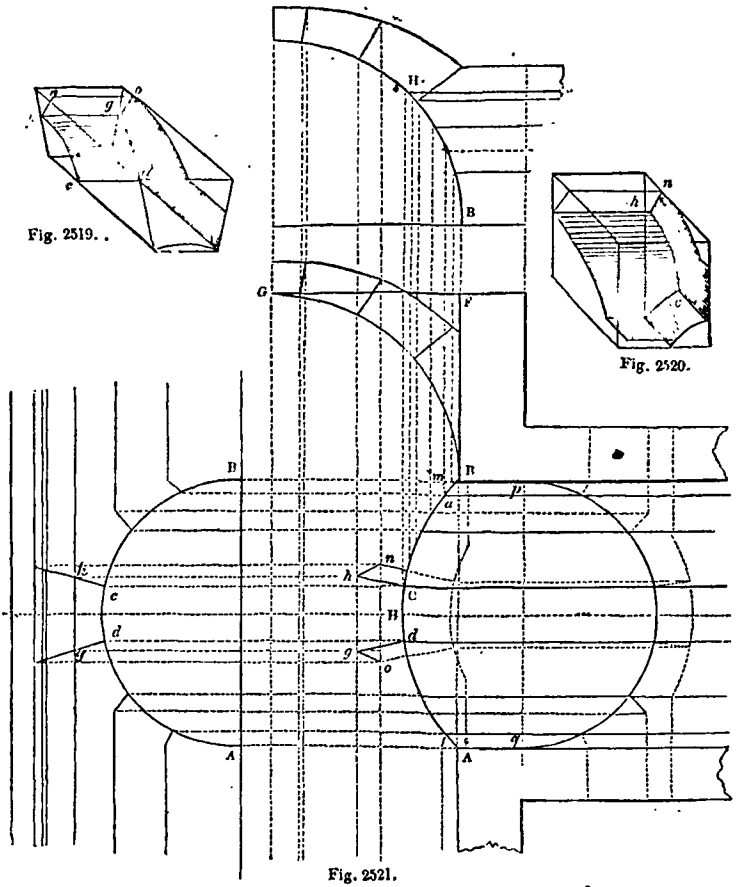


Fig. 2521.

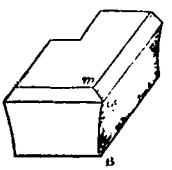


Fig. 2522.

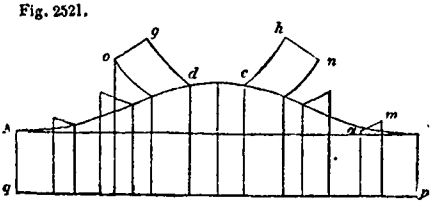


Fig. 2523.

where the smaller arch intersects; the voussoir underneath is the next in succession, and the lower one that of the springing: it is apparent by tracing the various lines, which parts correspond in plan and section, and the letters also indicate the position of the stones, as well as their development.

A similar Vault intersected by another in an oblique Direction. — The same method of setting out is applied to this kind; the stone in isometrical perspective is the springing stone at M T N. The development shows the portion of the arch comprised between the corresponding letters on the plan.

The acute angles are objectionable in this arrangement; greater strength is obtained by adopting the form laid down in the small figure A B C D.

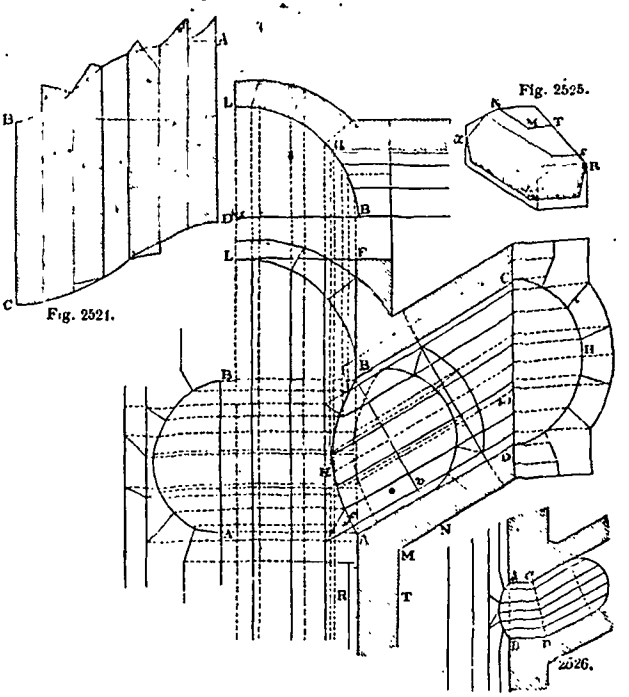


Fig. 2527. VAULTS OF DIFFERENT DIAMETERS CONNECTING OBLIQUELY.

Descending Vaults, intersecting at right Angles. — These are adopted to support the steps of a staircase, as well as to form its ceiling: by a reference to the letters on the plan and sections, as well as to the several stones shown in isometrical perspective, its construction may be understood. The springing stone, fig. 2531., the third voussoir, fig. 2529., the counter key, fig. 2530., and the key, fig. 2528., may have their several places found in the arch, by observing the letters on the plan and sections corresponding with them.

It has always been the practice with masons, when greater strength and security were required than could be obtained by the stone itself, to use metal cramps of different forms, adapted for the purpose to which they were applied: dowel, dovetail, and cauked or cogged are severally used to secure the joints both vertically and horizontally that are likely to be acted upon by the sliding or moving of any of the stones after they are bedded.

The Dowel Cramp is generally a piece of round iron, varying from ¼ inch to 3 inches in diameter, and from 1 to 9 inches in length, according to the dimensions of the stones; two holes are drilled into the contiguous faces of the work, exactly opposite to each other, and a little larger than the dowells to be inserted, which are either fixed in soft fluid plaster of Paris and water, or run with very hot molten lead: when the latter method is adopted, a small channel is cut out between the faces of the contiguous stones to introduce the lead, and a small cup or funnel is formed at the end of the channel with damp clay, into which the lead is poured from a ladle: care must be taken to cut this channel in a perpendicular direction, or obliquely to the back of the work, so that it may not be seen after its completion.

Dovetail Cramps are made of flat pieces of cast or wrought-iron, with the ends spreading out like the tail of a dove or swallow; a cavity of the same form is sunk half into one stone and half into the other, so that the cramp may be sunk rather more than its thickness into both, after which it is run with lead.

Descending Vault, intersecting obliquely. — In this example we are required to make another section to indicate the length of the joints, and obtain the development of the soffites; the great vault being oblique to this projection, the section through its centre is expressed by portions of ellipses, determined by perpendiculars raised from all the points

where the projections from joints on the plan cut with the horizontal line A B, and continued to the intersections of the joints of the new section. The three first voussoirs are

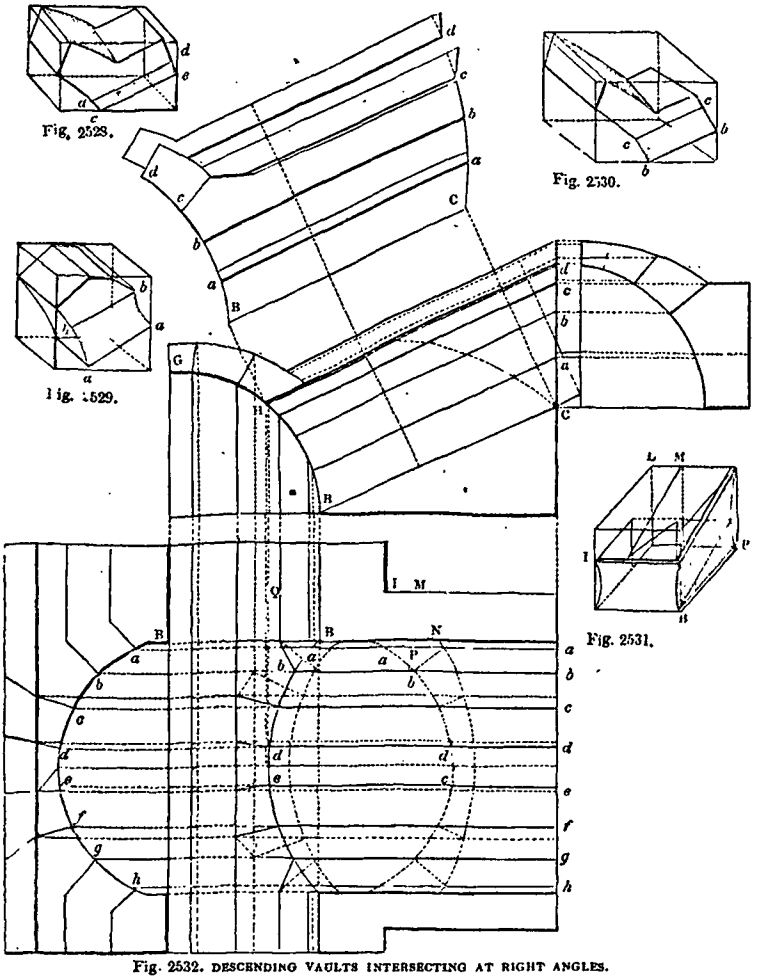


Fig. 2528.

Fig. 2530.

Fig. 2529.

Fig. 2531.

Fig. 2532. DESCENDING VAULTS INTERSECTING AT RIGHT ANGLES.

shown in isometrical perspective: the acute angles resulting from the double obliquity of the lesser vault, and the irregularity of the arris formed by the intersection requires the acute angle to be changed, as in a former example.

To construct a vault where both the extrados and intrados are conic surfaces having a common vertical axis, the solid being equally thick between the conic surfaces, so that in the joint lines those of the beds are horizontal, and those of the headings in vertical planes passing along the axis, the beds must be so formed that they will unite in horizontal planes, and the headings in vertical planes. As the sides of the joints of the courses of all vaults terminate upon the intrados in a horizontal plane perpendicular to it, if the intrados be cylindrical, the sides are straight lines parallel to the horizon, those of the coursing joints will be in planes intersecting the intrados perpendicularly in straight lines, and the course will form one solid prism; the sections will consequently all be equal and similar figures, and in vertical planes.

Groined Arches. — When on a rectangular plan, and formed by two vaults of the same height, but differing in diameter, the smaller arch being set out, and perpendiculars dropped to the diagonal or line of intersection, by drawing others at right angles to them, and setting off the heights of the several voussoirs of the smaller arch, we have several points, which traced through by hand give the curvature of the greater arch. To

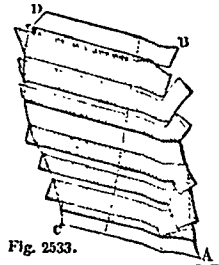


Fig. 2533.

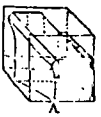


Fig. 2534.

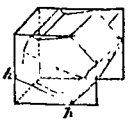


Fig. 2535.

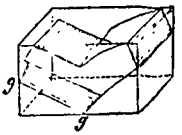


Fig. 2536.

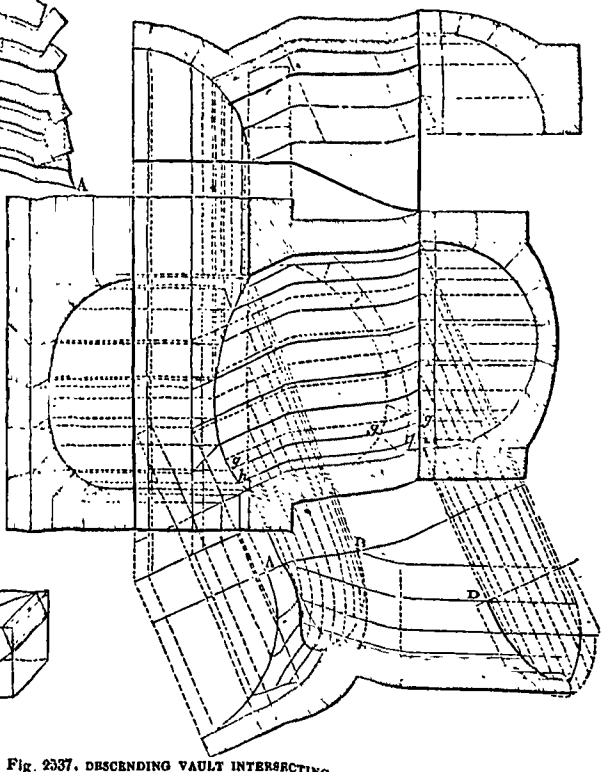


Fig. 2537. DESCENDING VAULT INTERSECTING OBLIQUELY.

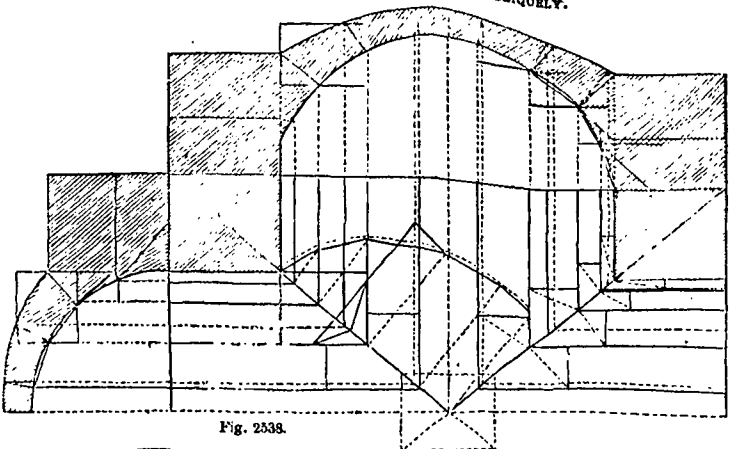


Fig. 2538.

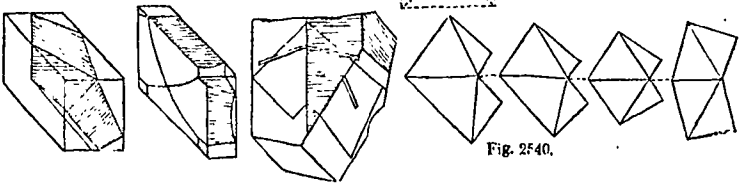


Fig. 2540.

Fig. 2539. GROINED ARCHES ON A RECTANGULAR PLAN.

indicate the proper curve of the groin over the diagonal line, at the points of intersection of the two perpendiculars already mentioned, draw others at right angles to the diagonal, on which if the heights are set, a line may be drawn through them, which will express its curvature. This latter method may serve to set out the stones of the greater arch, and less stone is used or wasted than by the first.

Groined Vault, on an irregular Plan. — The primitive form is a semicircle, drawn on the shortest side; on this is marked all the voussoirs, after which the others are set out, having an elliptical form. The diagonal line on the plan shows the position of the groins; each side is then divided into two equal parts, and lines drawn from them through the centre: from the primitive semicircle perpendicular lines are dropped from each joint, until they intersect the diagonals; at these points of intersection, lines parallel to the centre line on the plan are drawn, until they intersect its several sides; perpendiculars are then raised

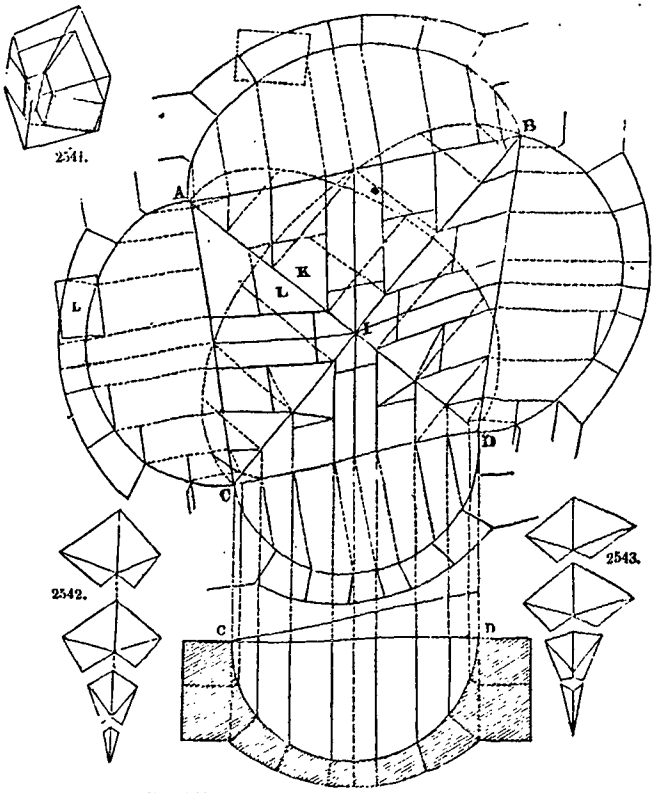


Fig. 2544. GROUND ARCHES ON AN IRREGULAR PLAN.

from these points, on which is set out the various heights; a line traced through them indicates the form of the respective vaults. The several voussoirs on the diagonal C I are shown to the left, and those on the diagonal D I to the right of the plan; the figure in isometrical perspective shows the stone K L.

In vaults of this description there are no groins or diagonal ribs, as was the practice of the Romans: in the concrete vaults which remain of their construction, as the Pantheon, Minerva Medica, and the Coliseum, a course of tiles or stone is generally introduced at the groin, which performs the office of ribs, and it was probably discovered at a very early period that there was a necessity for strengthening this part, and providing more security than could be attained by the arris joint.

Before we can construct vaults composed of stones, where each is to be cut into a particular form, we must be thoroughly acquainted with the rules by which figures may be projected, or with the principles termed by the French engineers descriptive geometry, by which every point in space is represented, and perpendiculars drawn from them to each of the planes of projection, the point where any perpendicular falls being the pro-

jection of that point: as a series of points in succession represent lines, the boundary of any figure may be arrived at and accurately defined in every position; by dropping perpendicular lines from the sections of an arch, the position of the several voussoirs on the plan are perceived, and their form may be traced according to their several positions, which vary as the stones approach or recede from each other.

Groined Vault, on an hexagonal Plan. — The primitive centre, from whence the rest is derived, is here a semicircle composed of seven voussoirs: after drawing the six diagonals from the opposite angles, and perpendiculars dropped from the arches to intersect with them, on either of the diagonal lines may be raised others at right angles, upon which by setting out the heights the curvature of the groin may be traced through. The central stone or key is set out on the plan, and its sides are perpendicularly cut, after which the mould of curvature is applied to mark out on its section the intrados and extrados: B is the central key, C represents the form of the other voussoirs.

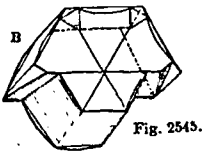


Fig. 2545.

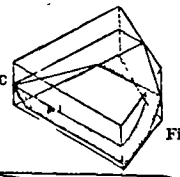


Fig. 2546.

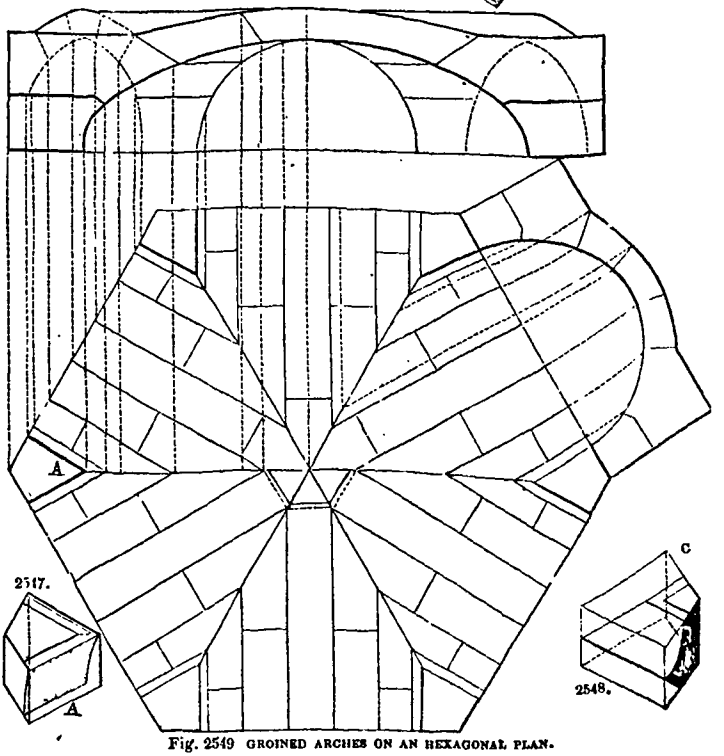


Fig. 2549 GROINED ARCHES ON AN HEXAGONAL PLAN.

In vaults of this description the pressures are reduced to six points of support, consequently buttresses or walls of considerable depth are required in the direction of that pressure, between which a very thin wall may enclose the building; this was the practice of the freemasons, who did not require their external walls to have one uniform thickness throughout, but applied the greater portion to resist the external pressure where it was most needed, and by this system of construction they greatly economised their material.

In the plan the position of every stone is laid down by dropping perpendiculars from the joints drawn in the section above, after which their dimensions can be obtained, and the mould taken, by which they can be accurately cut. To ascertain the form of all the plane

faces or surfaces by which stones are circumscribed at their junction edges or arrises, the method of projecting right lines in every possible position must be thoroughly understood; and no better study can be suggested for the mason than laying down upon paper the representation of the solids in various positions, by which he will acquire facility in comprehending this most difficult part of his art

Hexagonal groined Vaults, with pointed Arches or Ribs. — These are composed of parts of circles less than 90°, so arranged as to form different compartments; the intervals are filled in with small stones bedded in plaster or mortar. To cut the ribs two moulds only are required, one taken from the plan, which gives the upper and lower surfaces, and the other on the section for the profile of the height comprised between the intrados and extrados. The key is a truncated reversed pyramid, whose base is a hexagon inscribed in a circle, as in the right hand figure: we commence by cutting a surface, on which is set out the polygon, or base of the pyramid; its inclined sides are set out by taking the bevel; on each of these surfaces are drawn parallel lines, the first marking the contour of the joint at the extrados, and the other that of the intrados. The first stone of the ribs is shown at the bottom of the figure, and its section above: A is the keystone, and its plan is shown at B.

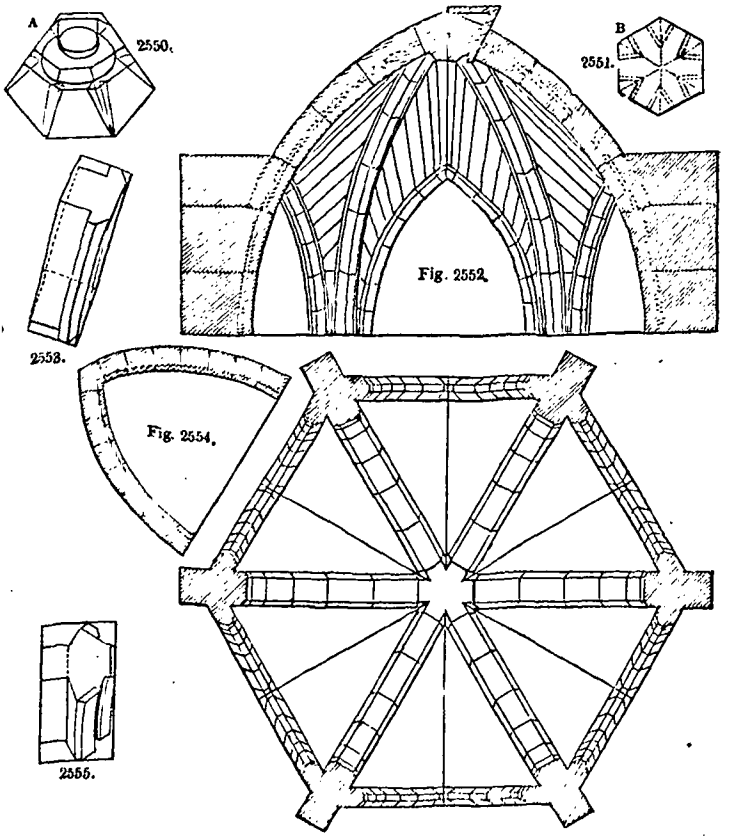


Fig. 2556. HEXAGONAL VAULTING WITH RIBS.

A great improvement was effected by the masons of the middle ages in the construction of polygonal vaults: the groins are always covered, as well as supported by ornamental mouldings, and the ribs so formed carry the vault above them; we may imagine the ribs, after they were built up, to constitute a centre or support, upon which the covering was to be laid, and a beautiful result is produced from the expression given to the construction, differing so materially from the former practice of concealing the ribs, or covering them up in the mass of concrete which constituted the vault.

We have several examples of light stone or chalk filling up the spaces between the ribs, sometimes laid to constitute an arch from one to the other, forming a groin in the centre of each compartment, or pitching against a smaller rib in the middle, producing

every imaginable diversity of figure: there can be no doubt that the Romans practised the various methods of groining in concrete adopted after the introduction of pointed architecture, with the omission of the rib, although there are several instances of it concealed in the thickness of their vaults; the flat tile is found built up in ribs, of which there are several remains in the springing of the vaults in the Temple of Peace at Rome.

Circular Vaults, with double Groining. — The primitive vault, from whence we commence setting out the voussoirs, is a semicircle; the others are ellipses formed from its ordinates: lines are let fall until they meet the diagonals, as is described in a former diagram; others are then drawn at right angles to them, to enable the setting out of the greater vault. The double groin is then drawn to the points of the right lines which cross the centre of the figure on the plan, at pleasure; where the perpendiculars are crossed by these groins, they are united at their points by other lines; these show the joints of the stones at the double groins. The four first voussoirs are at the side, and above is the vault, and on the right is the third voussoir, both in perspective.

The stones which compose vaults of this description are terminated by both plane and curved surfaces: some exhibit merely a point and two surfaces; others, one curved and one flat, the junction or meeting of which produces either a circular or elliptical arris common to both: such figures are very difficult to project, and must be considered as cones, which require several points to be laid down for the curvature forming their bases. A pyramid with an elliptic or circular base may serve to facilitate the projection of a polygon, and advantage will always be derived from a knowledge of the regular solids, when there is a necessity for setting out any curved lines, whether vertically or horizontally placed. In the work of Le Croix, the "*Complément des Elemens de Géométrie,*" the best method for projecting figures of this kind is laid down; and their careful study cannot be too strongly recommended to those desirous of arriving at excellence in the art of stone-cutting, which is decidedly much better understood on the Continent than in this country.

Fig. 2557.

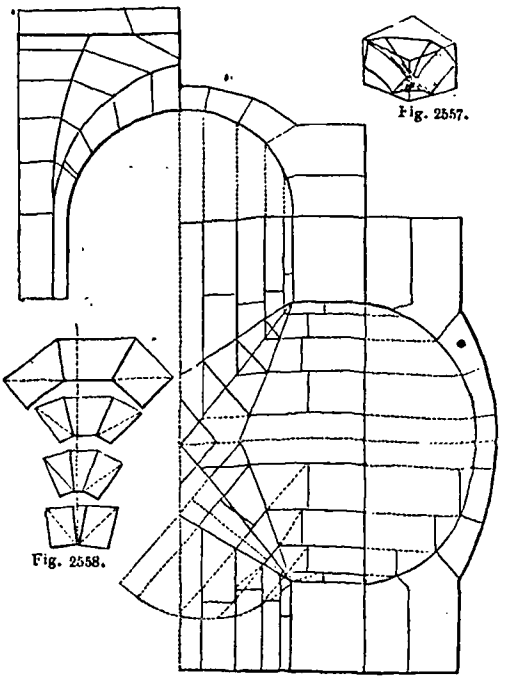


Fig. 2558.

Fig. 2559. CIRCULAR VAULTS.

When vaults of large dimensions are to be constructed, there is a considerable saving of materials as well as expense by the engineer making his contract with the proprietors of the stone quarry for the delivery of blocks of certain forms and dimensions, for which purpose a sketch of the forms of the stones will be required, with the several dimensions; and after the quarryman has roughed them out, he puts numbers upon them corresponding with those of the drawing; each stone being thus dressed somewhat to its intended shape is reduced in weight, and expense of transport is considerably lessened: the numbering upon the stones should commence with those to be first used, and be regularly proceeded with to the last. Where a series of arches is to be constructed, the voussoirs may all be got out of the quarry in the same manner, and much of the after labour be dispensed with: no general rule can be given for the dimensions of the various stones to be used, but the blocks should be as large as possible, as the strength of all masonry depends as much upon the weight as upon the quality of stone; large and heavy stones with few mortar joints constitute the best construction. We have already observed that the Egyptians and Phœnicians used stones of greater size than are to be found in any modern buildings, and our astonishment is naturally excited to the manner in which they were enabled to move them to the situations in which they are placed: whenever great strength is required, solid

masonry should be employed; the piers of bridges and vaults which have to resist considerable pressure should be formed of carefully selected stone, and of a quality free from all fissures and cracks, and care should be taken that when placed the under sides of all the beds are perfectly smooth and level, which is not always done, less attention being paid to them than to the upper bed, which is always in sight, and more easily worked: the engineer who is desirous of having his work solid should observe that every stone is bedded perfectly flat, and placed at right angles to the side that is to form its external face throughout the whole depth, and not merely for a few inches within the joint, as is often permitted; there should be perfect contact between the several stones in every direction and on every plane, and no vacuity or space allowed to be filled in with cement or mortar: for the vaults of buildings used as warehouses where heavy weights are deposited, the masonry should be constructed with the greatest care and solidity; but for the covering of a nave or side aisles of a cathedral or church, where no extraordinary additional weight is to be supported, this solidity may partly be dispensed with.

Gothic Vault, with three Ribs in each Compartment, uniting at several Keys. — The centres of these ribs are always in a horizontal plane, which passes through the springing. The plan of the ribs being given, we first set out the centre G H, passing through the middle of the sides which form the plan; after having drawn the chord G H, draw a perpendicular through its centre to the point L. This point is the centre from which the arc G H is to be struck. To obtain the rib I N, prolong their centre to O; then set off F O from the plan on the elevation from P to *b*; through the point *b*, draw a parallel to the axis R P, which will cut the arc G H in *d*, and give the height *b d* for the arc I O.

To have the curve of this arc, take for base the diagonal E F on the plan; set off I O from E to *q*, and after having raised the perpendicular *q g*, equal to *b d*, draw the chord E *g*, on the middle of which raise another perpendicular, which will cut the base E F prolonged in *h*; this will be the centre of the arc E *g* raised perpendicularly on E *q*, and equal to I O: but as it must stop at N, we shall obtain its true length by setting off O N from *q* to *n*, and drawing through the point *n* a parallel to *q g*, which will cut the arc E *g* at *i*, and E *i* will be the arch represented by I N.

For the parts of the ribs which intersect the others, as F N on the same base E F, describe the pointed arch E H, whose height F H is given; then set off F N from F to *p*: having drawn through *p* a parallel at F H, set off from *p* to *k* the height *n i* of the intersecting ribs, and having drawn the chord *k* H, raise on its middle a perpendicular cutting the base E F in *t*; this point will be the centre of the arch forming the intersecting rib, whose length is expressed by *k* H. The arc forming the other rib N D is obtained by setting off

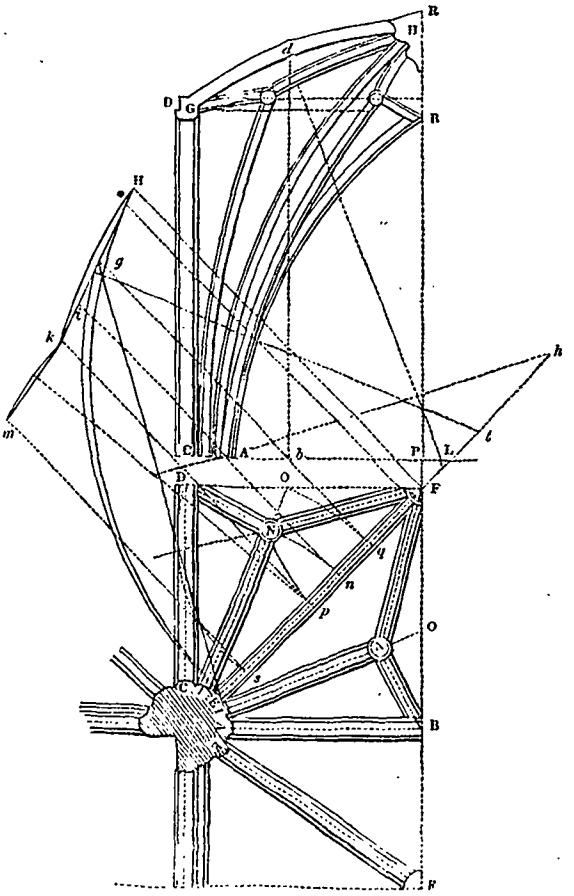


Fig. 2560. GOTHIC VAULTS WITH RIBS.

N D from p to s, and by raising through this last point a parallel pk, on which is set off the height C G, taken on the section from s to m; and having drawn the chord km, raise on its centre a perpendicular cutting the base E F in a point, which is found as p; it will be the centre of the arc mk, answering to D N.

To facilitate the drawing of ribs of this kind of vault, the diagram may be referred to, where their various forms are divided into voussoirs. The keys being the parts which require the most care should be set out with reference to all their projections.

Hanging Keys.—The last voussoir of arches of this kind, having their abutments against the principal key, form together one independent of that which constitutes the centre; this has given the idea of suspending keys, as well as those hollowed out, found in many vaults of the middle ages, which have excited astonishment in all who have beheld them.

The filling in between the ribs forms surfaces of double curvature, which would be very difficult to execute, if not sufficiently small to be supported by plaster or mortar, and to follow the curvature of the arcs without its being necessary to cut them expressly.

Gothic Vaults, formed of four quadrants of an inverted concave parabolic conoid with a central key, are the perfection of the mason's art, and we have examples of them of great beauty in buildings constructed during the fifteenth century in England. If a cone of this form be constructed upon its broad base, with rings of voussoirs, in the same manner as for a dome, their vertical joints diverging to a vertical line drawn through its centre, it will stand in a similar manner; when the conoid is so constructed, if it be stood upon its apex, and the base prevented from spreading, the voussoirs will retain their position. We may imagine such a figure cut into four parts, each having one flat side against the wall of the building and the opening formed by the four quadrants of outer voussoirs, which constituted its original base, filled in with

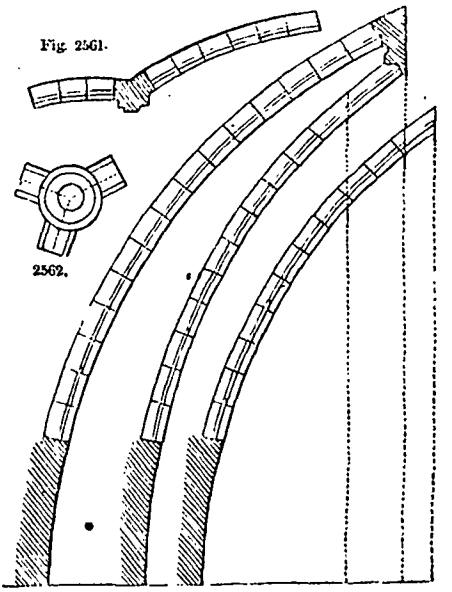


Fig. 2563. RIBS OF GOTHIC VAULTS

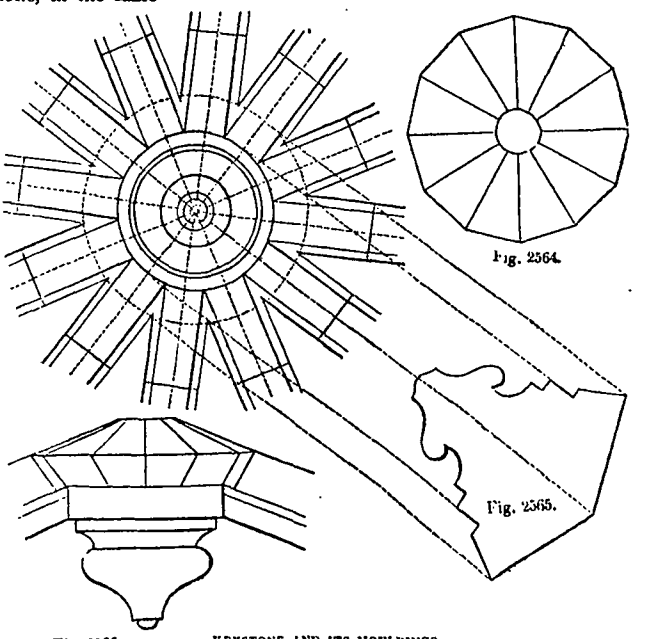


Fig. 2566. KEYSTONE AND ITS MOULDINGS.

a large block of stone or a central key, to keep them in their place, and to lock them together, which would form a very solid vault, and is the principle of keyed ribs.

When four arches raised on the sides of a square, as in the compartments of a cloister, traverse each other, and unite over the centre, they are called

The Voute d'Arete and *Arc de Cloitre*, and are composed of triangular portions of a semicircular vault: in the first, each of these parts only rests on two of their angles, as A, while in that of the arc de cloitre each triangular part, E D C, has for its base one of the sides, which rest

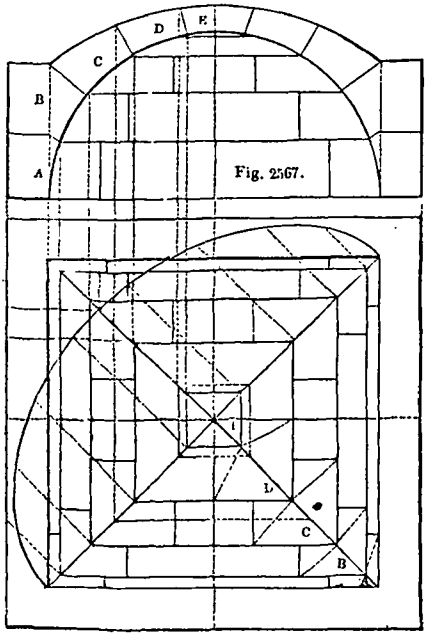


Fig. 2568. ARC DE CLOITRE ON A SQUARE PLAN.

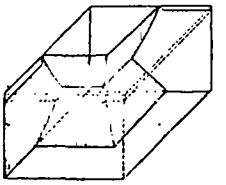


Fig. 2571. VOUSSOIR AT B.

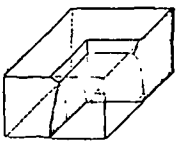


Fig. 2572. FIRST VOUSSOIR.

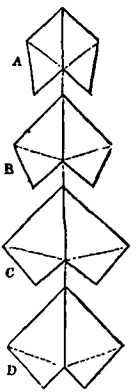


Fig. 2573.

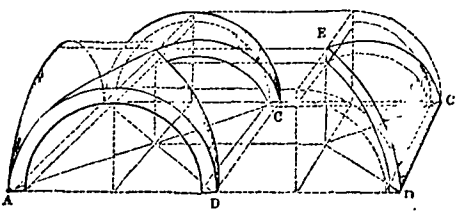


Fig. 2569. VOUTE D'ARETE. Fig 2570. ARC DE CLOITRE.

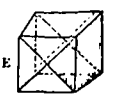


Fig. 2574. KEYSTONE.

on the wall throughout its whole extent: each part of the vault in the arc de cloitre is formed by portions cut from two intersecting semicircular vaults of the corresponding voute d'arète, that is to say, agree in figure and dimension.

Arc de Cloitre, on a square plan, having its primitive centre a semicircle, shows the joints of the several voussoirs; the drawn lines indicate the intrados, and the dotted the extrados.

The rows of voussoirs inscribed on each other form hollow squares, subdivided by joints perpendicular to their sides: this projection serves to find the base of the prisms in which each voussoir is contained. The section indicates the form of the several stones.

The four examples of development at the sides show the intrados of the voussoirs forming the re-entering angles which characterise this kind of vault; the voussoirs are indicated on the plan and section by the several letters, A, B, C, D, and E. The upper figure in perspective is the voussoir marked B, the other is that marked A.

Vault of Arc de Cloitre with an Octangular Plan. — The general setting out is the same as in the previous figure. The primitive centre is a semicircle, as seen on the section, which when

lengthened out forms the ellipsis on the plan. The voussoirs of the angle, instead of being comprised in parallelepipeds with a square base, are contained in a prism with a pentagonal base; the key is a portion of a truncated octagonal pyramid, whose bases are formed by an assemblage of triangular portions of curved surfaces, concave below and convex above.

The Arc de Cloitre on an irregular Plan has a less solid form than others, and ought never to be used; when adopted, the operation of constructing it is tedious, but not difficult. The rows of voussoirs should be always parallel to the walls, so that the key has the same form as the plan; the projections on the plan give for regular vaults the bases of the prisms in which the voussoirs are comprised; the sections perpendicular to each side, through the centre, give the profile of the moulds at the several joints; the only difference is, that in regular vaults it is sufficient to draw out a single side, the others being similar, while in irregular we must draw each, as they are all different in form, and as the distance from the centre of the key to the walls is unequal, different curves result, but they are only prolongations of that which has the least radius, considering it as the primitive centre.

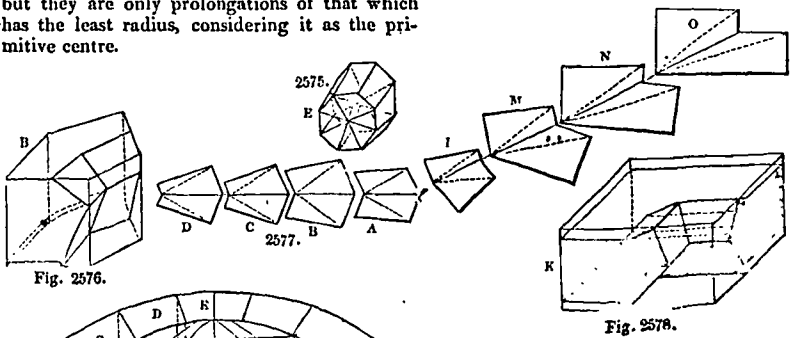


Fig. 2576. Fig. 2578.

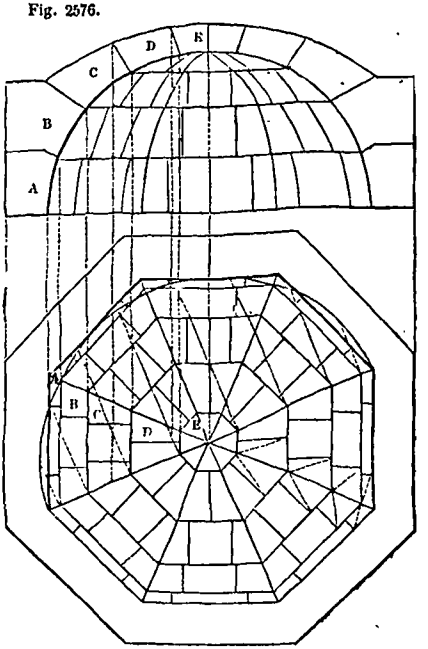


Fig. 2579. ARC DE CLOITRE WITH AN OCTANGULAR PLAN.

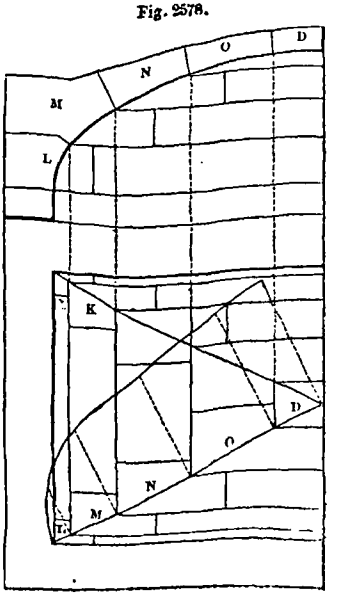


Fig. 2580. ARC DE CLOITRE ON AN OBLONG PLAN.

Vaults of Arc de Cloitre, on an Oblong Plan. — On the section the form of the several stones L, M, N, O, D is shown, and the plan of their intrados below; K is the second stone at the angle, in perspective. In this example the re-entering angles correspond to the diagonals of the rectangular plan, which makes the centre over the lesser side of greater length, when drawn out, than that over the greater, which does not produce a good effect; therefore it is preferable, when an oblong square is to be vaulted, to make the middle portion semicircular, and the angles 45°, which gives an equal curvature to all the sides.

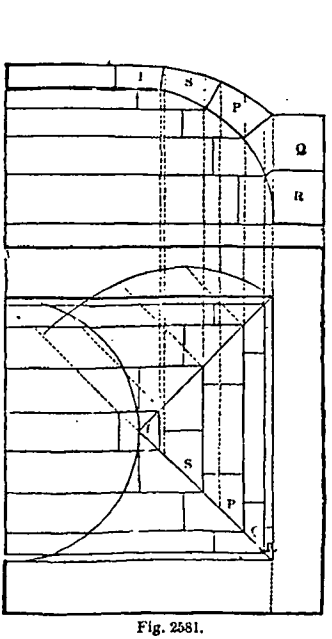


Fig. 2581.

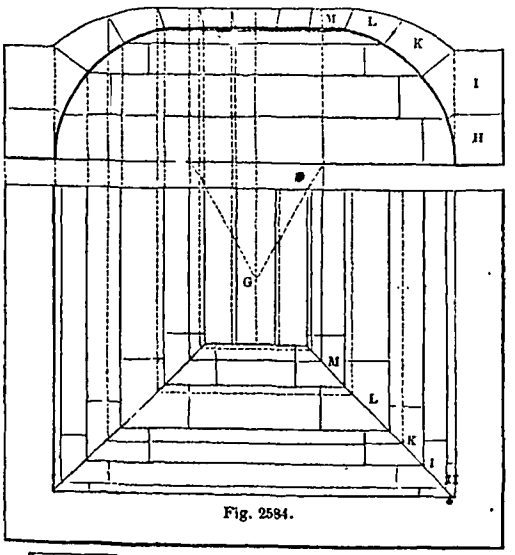


Fig. 2584.

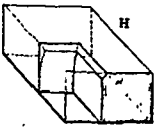


Fig. 2585.

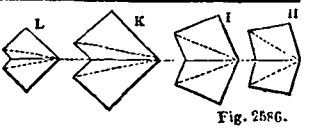
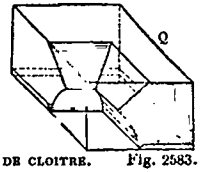


Fig. 2586.

2582.



ARC DE CLOITRE. Fig. 2583.

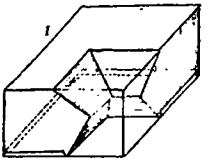


Fig. 2587. ARC DE CLOITRE WITH A FLAT TOP.

Vault of Arc de Cloitre, with a flat top, called by the Italians *Volta a Concha*, is used in large rooms; the form which has the best effect is that which results from dividing the breadth into three equal parts, giving two to the vaulting, and the other to the middle platform: to give this vault all the strength possible, it is necessary to pay particular attention to the direction of the joints of the level part in the centre; setting out the width of the platform on the base of the section, and then forming upon it an equilateral triangle, we obtain the point G, to which all the joints of the centre compartment tend.

All that has been previously described will apply to this vault; the re-entering angles being all similar, it is sufficient to make the mould for one, as indicated by H, I, K, L, M, which show the form of the intrados of the several stones marked on the plan. H is the springing voussoir, and I the one resting on it.

Where vaults are constructed entirely for ornamental purposes, the thickness of the voussoirs may be very small in some instances: at the Chapter House at Wells, they are not more than 3 or 4 inches; particularly in the panels between the several ribs, tufa, chalk, and stone of light weight is selected, to prevent any pressure or thrust against the outer walls or their abutments, which in several buildings is entirely resisted by the weight thrown vertically upon them. The masons of the middle ages knew well how to calculate these vertical and lateral thrusts in all their constructions, and seldom used more material than was absolutely necessary to produce the effect they aimed at; the spandrills of their arches were kept from springing by a mass of rubble; in some cases we find the whole spandrill formed of one large stone tailed into the wall, and maintained in its position by the weight of several courses of masonry placed upon it; in the construction therefore of vaults like that of the arc de cloitre, centering is only required for the voussoirs marked C, D, and E, in fig. 2567., or N O D, in fig. 2580., where the plan is an oblong: by a

judicious extradossing, vaults of this kind may be made almost to balance themselves, and to exert but little thrust, certainly not more than can be overcome by a weight put upon the external walls, or that deposited by the timber roof, which usually covers the entire building.

Conical Vaults have their interior surfaces parts of cones; the most simple are those constructed on two walls, forming an angle, so that the centre of the face represents the base of the cone.

All the joints tend to the apex of the cone, diminishing in breadth; but if continued throughout, they would become too weak, therefore a single stone is adopted, called a *trompillion*, A. To form the voussoirs we must first set out their horizontal projections, their vertical and their profile or section, which are shown in the elevation, plan, and the development of the diagram.

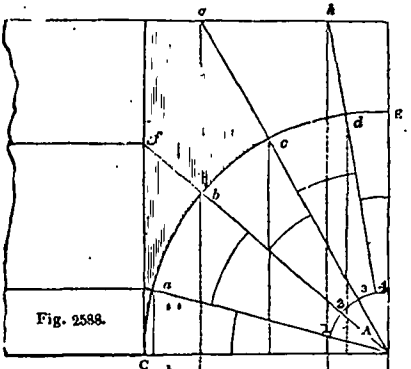
To transfer the moulds of the intrados, joints, and beds, with the bevels of the angles formed by the union of the surfaces to which these moulds are to be applied; the workman should take care to select the greatest face as a base from which to set out the others: thus in *trompes* he commences with the intrados of the voussoirs, and dresses a face preparatory to applying the mould.

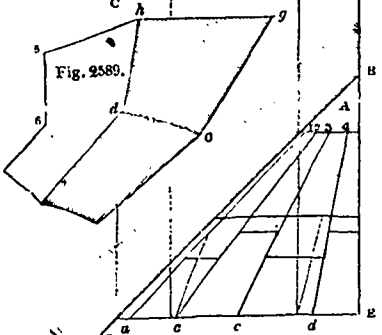
In the example given the development is a semi-cone or sector of a circle, whose radius is equal to B C on the plan, and whose arc is equal to the development of the semicircle which forms the face; whence it results that each intrados is represented by a small sector or isosceles triangle, whose base is formed by the arc, or by the corresponding chord of each voussoir, and by two radii or sides equal to C B.

If from the entire development, or from that of each intrados, we cut off the part answering to the trompillion, the surplus will be the entire intrados, or each part of the intrados; thus the intrados of the trompe is expressed in the development by C, *a*, *b*, *c*, *d*, E, *n* 4 3 2 1 0, for one half, the other being perfectly similar.

The moulds for the joints are supposed to be laid flat on the development of the intrados, and attached to the side to which they have reference; thus the mould (fig. 2591.) 5, 6, 7, 4, *d h* is that indicated by the line *h d* 4, shown on the elevation, and *g c* 3, 10, 9 8, answers to the line *g c* 3 : *f b* 2, 11, has reference to *f b* 2 on the elevation, and *e a* 1 *v* to *e*, *a*, 1. This result being formed of a right cone, hollow, and of equal thickness, the angles of all the joints taken perpendicularly to the intrados are all equal.

To find these angles, observe that the voussoirs are supposed to be divided on a circle, whose radius is perpendicular to the inclination of the inner surface of the cone, and drawn from a centre placed on the axis; by a reference to the figures and letters on the elevation, plan, and development, the whole setting out may be understood, difficult as it may appear.





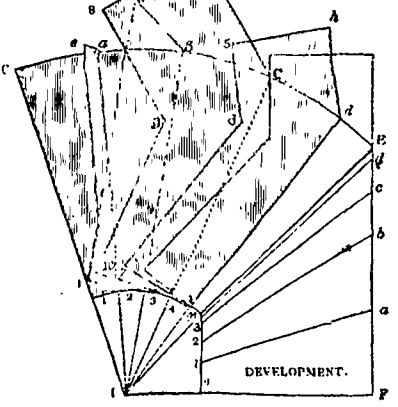


Fig. 2591. CONICAL VAULTS.

To construct a Trompe in an Angle raking with a salient Angle.—This is a prolongation of the preceding problem, cut by two vertical planes forming a right angle. The word *trompe*, which has been so frequently made use of, is a peculiar feature in French architecture of the time of Philibert Delorme, who describes it as signifying a projecting vault supported in the air, and derived from the shell called the sea-trumpet; or because it is deceptive, its construction being hidden. It is variously used, both on exterior and interior angles, in niches, or in round towers projected to contain a staircase:

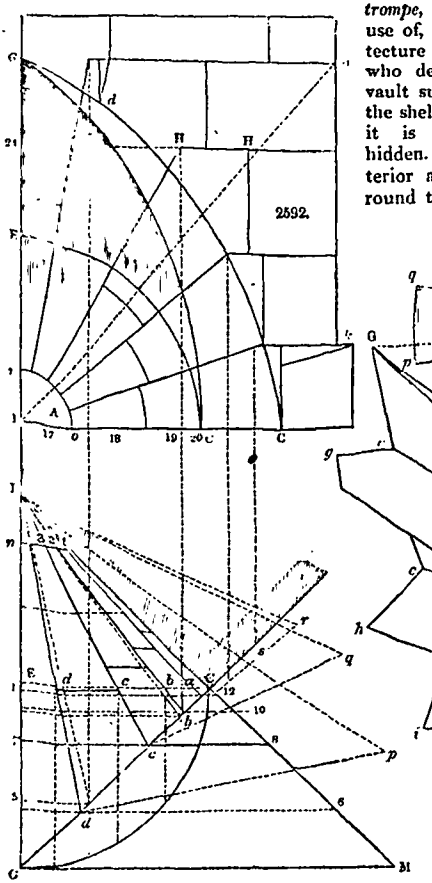


Fig. 2593.

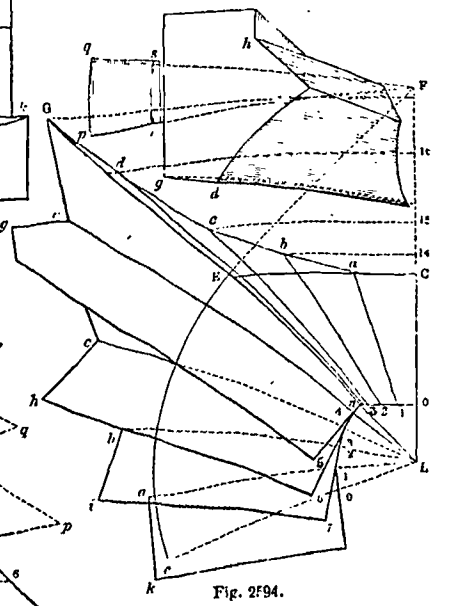


Fig. 2594.

TROMPE ON AN ANGLE.

that called the Trompe de Montpellier was one of the most celebrated. Having divided the voussoirs on the quarter circle, E C, of the elevation, whose projection is seen on the plan at EC, and transformed to this line the divisions of the quarter circle, by others parallel to the axis G L, we must draw through the points *a, b, c, d* the point L, representing the apex of the cone on the plan, right lines from *n o*, which indicate the projection of the circle, forming the trompillion to G C, indicating the projection of one of the faces of the angle. These lines will show on the plan the joints of the several voussoirs which form the trompe, and the face of their intrados: to obtain their elevation, draw from the point I, indefinite lines, passing through the points of division of the circle *d c b a*. To determine their extremity and height, observe that this trompe being formed by a right cone, whose axis G L is level, if we prolong the side L C to the intersection of the perpendicular G M, with the axis L G, the angle of the trompe raised perpendicularly above G will be in the middle of a semicircle, whose radius will be G M, and which will be the base of a cone prolonged to the line G M: thus the height of the angle G should be equal to the radius; whence it results, that to have the extremities of the joints of the intrados, which terminates at the edge of the trompe, we must draw through the points *d, c, b, a* of the plan, lines parallel to G M, which will indicate the radii of the semicircles in which the extremities of these joints are found. Then from the point I at the summit of the cone, on the elevation, with a radius equal to *5 d 6* of the plan of projection, make the section, which will cut the joint *4 d*, prolonged in *d*: from the same point, I, with a radius equal to *7 c*, make another section, which will cut the joint *3 c* prolonged in *c*: the points *b* and *a* may be obtained

in the same manner with the radii 9 *b*, 10, 11, *a* 12 of the plan. Through the points G, *d*, *c*, *b*, *a*, C, draw a curve, which will express the edge of the trompe foreshortened: to have this curve without foreshortening, take the breadth of the line G C on the plan; being the result of a plane cutting a cone parallel to the opposite sides, it will be a parabola.

To draw the profile represented in the development, which indicates the section of the trompe taken on the axis L G, on the plan: first make the base line, L F, equal to L G; then from the point F raise a perpendicular, F G, equal to I G on the elevation, and draw the oblique line L G, which gives the inclination and real length of the line passing through the middle of the key: then set off L *n* from the plan from L to *o*, raise the perpendicular *o n*, which gives the vertical projection of the circle terminating the trompillion. In like manner set off L E from the plan from L to C, and raise the perpendicular C E, representing the projection of the quarter circle, E C, on the elevation: having then set off on this line the heights 17 *d*, 18 *c*, 19 *b*, and 20 *a*, from C to *d*, *c*, *b*, and *a*, draw these points to L, the summit of the cone; the indefinite lines will represent the joints of the intrados, to terminate which, and to indicate the curve at the edge of the trompe, set off the points E, 11, 9, 7, 5, from the plan, from C to 13, 14, 15, and 16, through which raise the perpendiculars, cutting the joints of the intrados in the points *a*, *b*, *c*, *d*, through which and the point C G draw a curve which terminates these joints, and shows the edge foreshortened.

Development of the Moulds for the Intrados and Joints.—The intrados of the trompe being oblique in two directions, cannot be wholly expressed either on the plan, elevation, or section: to find their elongation, it must be remembered, that the length of a line inclined to the plane of projection depends on the difference of the perpendicular distance from its two extremities to this plane, which gives in every case a right-angled triangle, whose vertical and horizontal projections give the two sides forming the right angle; so that the hypotenuse of this triangle always presents the real length of the foreshortened line.

In the figures which represent this trompe, the projection of the joints of the intrados of the plan, and the heights given by the elevation or the profile, express the sides of triangles which answer to each joint, represented as foreshortened; thus, to have their real length, we raise, from the points *d*, *c*, *b*, and *a* of the joints shown on the plan, perpendiculars to each of the lines which represent them: the corresponding heights are set off at *d*, *p*, *c*, *q*, *b*, *r*, *a*, *s*; then through the points *p*, *q*, *r*, *s* lines are drawn to L, which give the true length of the joints of the intrados prolonged to the point of the cone: knowing these lengths and the chords *G d*, *dc*, *c b*, *b a*, and *a* C of the centre of the developed face forming the edge of the trompe, we obtain the three sides of the triangles forming the moulds of the intrados prolonged to the summit of the cone, and they are united in the development, where they are indicated by the letters L, *d*, G for the half key, and L *cd*, L *cb*, L *ab*, L C *a*.

The moulds of the joint are placed on the corresponding lines of the intrados to obtain a greater solidity: they are of equal width, and their lower angle is a right angle, that is to say, perpendicular to the slopes of the intrados, so that it only remains to find the elongation produced by the obliquity of the joint of the intrados with the face. To obtain this elongation, take on the plan the length of the line L *g*, which represents the projection of the diagonal of the joint mould of the key, indicated on the elevation by *dg*; set off this length from G to 21 on the horizontal line passing through *g*, and take the distance in a right line from 1 to 21, which gives the length of the diagonal required: with this length, from the point L describe an indefinite arc, intersecting another, described from the point *d* with a radius equal to *dg*, taken on the development of the curve forming one of the two edges of the trompe, on the elevation; having then drawn a parallel to L *d*, to mark the width of the joint, till it intersects *dg* prolonged, cut off by a line drawn from *g* the point of the mould intercepted by the level joint. To have the direction of this line, take the length L *d* on the plan, with which, from the point L of the development, describe the arc of a circle, intersected at the point 23 by another described from the point *d*, with a radius equal to the perpendicular height of the point *d* above the horizontal line F C on the elevation.

To have the mould of the joint, indicated on the plan by L *c*, and on the elevation by *ch*, take, as in the preceding, the length L *h*, which indicates the projection of the diagonal of this joint; set it off from 24 to 25 on a horizontal line of the elevation passing through *h*, to have the distance I, 25, which will be the length of the prolongation of the diagonal: with this length as a radius, from the point L of the development describe an indefinite arc, intersected by another, described from the point *c*, with a radius equal to the joint of the head, *ch*, of the centre of the face prolonged: from the point of intersection, *h*, draw a parallel to L *c*, to determine the breadth of the joint, terminated by a perpendicular raised from the point 3, which forms the section of the base. The two other moulds of the joints are found in the same manner: it is sufficient to draw on the stones which form the voussoirs the bevels which give the angles of the intrados with

the joints; to these may be united the moulds of the head, taken from the centre of the elongated face, G c C, of the elevation. The figure in perspective is one of the voussoirs adjoining the key.

Trompe under a Round Tower, in a re-entering Angle. — This is a cone cut by a circular plane, shown on the plan by G *dba* C; the voussoirs are divided on the elevation in the quarter circle, B *dcba* C, which presents a section of the cone, through the line B C on the plan.

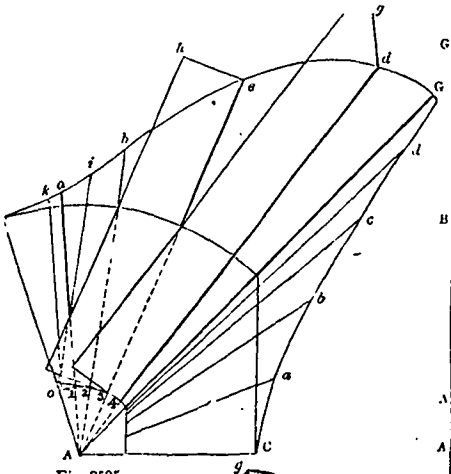
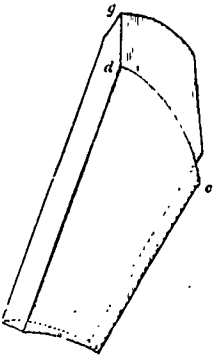


Fig. 2595.



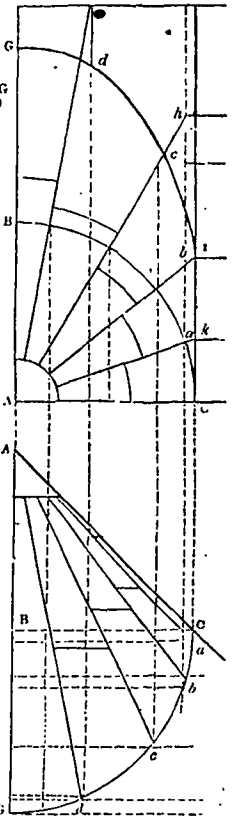


Fig. 2596. TROMPE UNDER A ROUND TOWER. Fig. 2597.

The projection of the joints of these voussoirs being prolonged on the plan to that part of the circle forming the round tower, and indefinitely on the elevation, to determine the extremity of these joints in the double curve which forms the edge of the centre of the face, draw, as in the preceding, from the points *a*, *b*, *c*, *d*, lines perpendicular to the axis, till they meet the side A C prolonged. It is evident that those lines are the radii of circles which pass through these points: with these radii, describe from the centre A of the elevation, sections *dcba*, which cut the corresponding joints in the perpendicular on the plan, indicating the extremities of the joints of the intrados, and those of the curve of the centre of the face. Knowing the heights and projections, it will be easy to draw the profile indicated by the development, and the moulds of the intrados and joints, by operating as in the preceding example.

It must be observed that, whatever be the contour of the trompe on the plan, that is to say, straight, angular, round, polygonal, or undulated, as in the example at the Chateau of Anet in France, the heights projections, and elongations of the lines and surfaces are found in the same manner, by supposing sections parallel to the primitive centre, perpendicular to the axis of the cone, whatever be the curve of this centre: the operation becomes longer and more complicated as the contour is more or less regular, or as the cone is more or less oblique. The stone in perspective is one of the voussoirs adjoining the key.

Trompe Circular, on plan erected on a straight wall. — This may be taken as an example of voussoirs sustaining a round tower. The utmost projection which may be given to the part of the tower it sustains must not be greater than two-thirds the radius of its outer circumference, and the centre of the voussoir must have a greater height than the projection.

To find the curve of the voussoir or vault, the primitive centre is shown on the elevation, as the base of a horizontal half cylinder, cutting another of greater diameter placed vertically, and which serves to represent the tower; the curve formed by the intersection of these two cylinders is the arris of the voussoir.

This curve being symmetrical and double, if right lines are drawn from all the points of one half to the other, they will indicate the surface of the voussoir which sustains the tower; we shall have the profile of this voussoir by drawing from the division points *a, b, c,* of the primitive centre, lines parallel to the vertical on the plan, and other horizontal *aa, bb, cc,* on the section. The distances are set off at 1*c*, 2*b*, 3*a*, on the plan at C 1, C 2, C″ 3 on the section; through these points raise perpendiculars, which will cut the parallels drawn from the elevation in the points *a, b, c.* These points of intersection will indicate the curve of the section of the voussoir, and more exactly as the division points are multiplied.

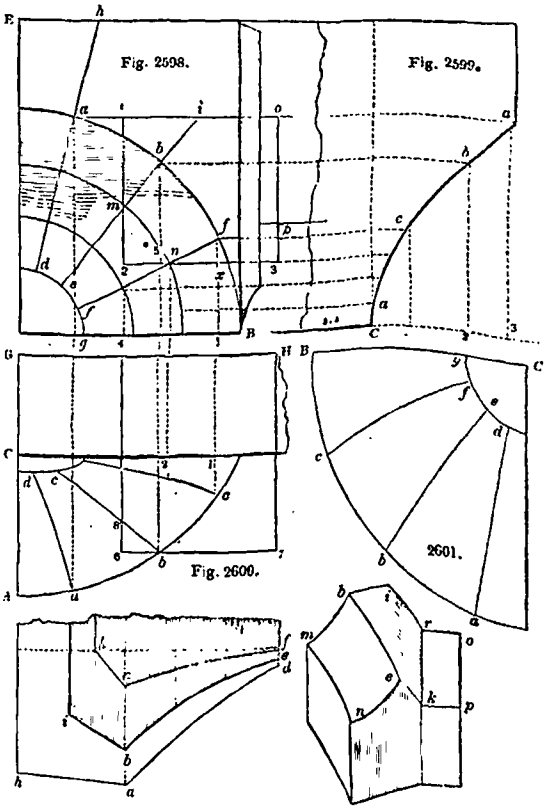


Fig. 2602. CIRCULAR ON A STRAIGHT WALL.

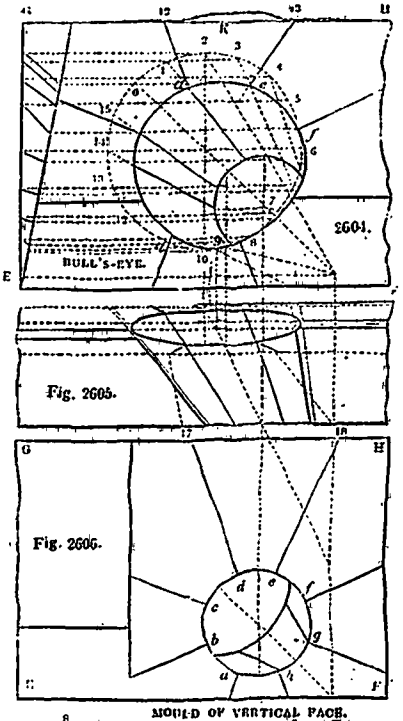
To draw the voussoirs which form the trompe, begin by cutting on each its largest face; then for the second voussoir, which we suppose to form the thickness of the wall, get out the square mass 1230 in the elevation, and 4567 on the plan. Take the mould *mionkp*, expressing the contour which it will form on the surface of the wall, indicated on the plan by G H, and the mould 486, B 95, of its projection on the plan; having cut the two straight surfaces at a right angle, apply the mould *mionkp* to one of them, and 486, B 95 to the others.

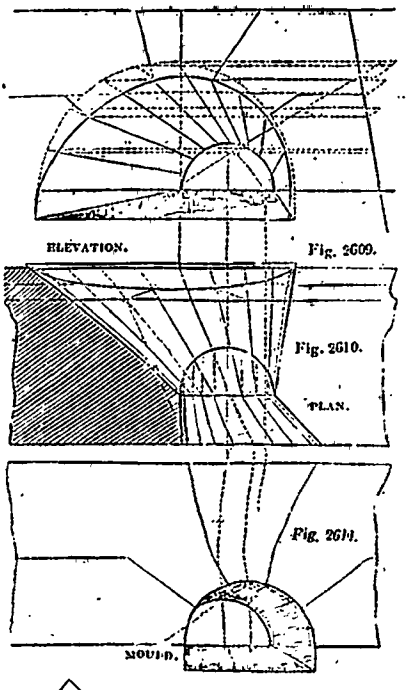
After having cut the joints *mi* and *nk*, apply the mould *kcfibe* to trace their contour: according to which and that drawn on the upper bed *io*, the stone is cut to form the convex surface of the part corresponding to the tower, which should be square with the bed above. The surface *mb nc* is formed with a curve taken from the section, placed always vertically, as the lines *bs, tv, cx* indicate: the curved joint *mn* is hollowed perpendicularly to the inner face of the wall; this voussoir is shown in perspective.

Skewed and inclined Arch in an inclined Wall. — The interior of a round window or bull's-eye presents the surface of an oblique cone with a circular base; the joints of the intrados of the voussoirs with which it is formed all tend to the summit of the cone, and the joints of the face to the axis; from the double obliquity of this cone, the vertical face alone, and the two horizontal beds, E F, G H, give the real size of the moulds and the joints; the development of the intrados is performed in a similar manner to that of oblique cones.

To trace the voussoirs, for example, of the bull's-eye or the key K, we must apply the

mould 17 *de* and 18, of the vertical face, which will give its greatest height, and that of its horizontal bed 12 13, 17 18, representing the extrados on the plan, which gives its greatest length. Having then faced the stone, square with the bed, the mould is placed on it, to draw the head of the voussoir and that of the extrados; on this tracing we may cut the two joints, these moulds giving their double obliquity; it is only necessary to find the two other lines, which should terminate them at the intrados, and on the side of the sloping face; this is done by cutting the second face with the bevel of the obtuse angle, which the surface of the extrados forms with the talus of the wall; the head mould, 12, 13, *ed* is then applied to finish the tracing of the voussoir; this process may be applied to the others. The development is seen below, as well as the key in perspective.





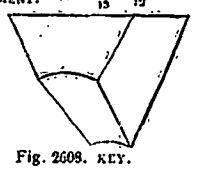


Fig. 2608. KEY.

Fig. 2613. CONICAL VAULT DOUBLY SKEWED.

Conical Vault doubly skewed, and splayed in a Wall having an Inclination. — The voussoirs may be traced in a similar manner, as in the preceding example. The voussoir in perspective is formed by dressing the vertical face at right angles with the extrados; the mould is then applied, and the mould of the extrados on the horizontal plan; then with a bevel the second face is cut, on which the mould of the sloping head is applied, and the stone dressed accordingly.

Spherical Domes are formed on the plan and elevation by semicircles; the interior surface of this kind of vault presents the effect of a reversed bowl, which has given them the term cupola, when of large diameter, as those which terminate as domes. The best method for setting them out is by horizontal courses, forming concentric crowns. Fig. 2617. shows the plan of the soffites of the courses of voussoirs of the vault above; it is set out in the same manner as it would be for a sphere. Supposing the interior surface of each course of voussoirs to be formed of a portion of a truncated cone, the sides of which are represented

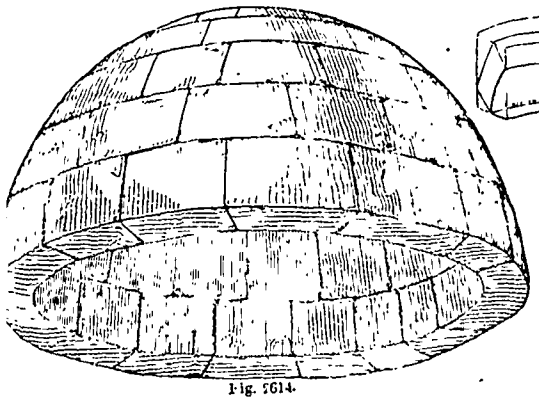


Fig. 2614.

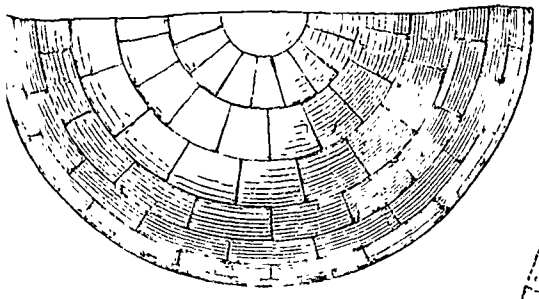
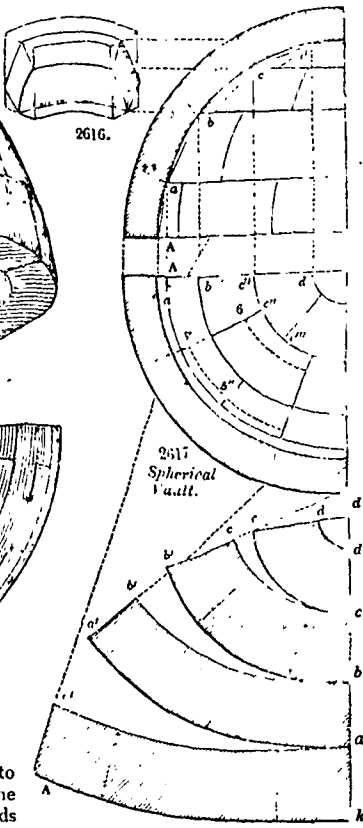


Fig. 2615.



2616.

2617 *Spherical Vault.*

Fig. 2618. DEVELOPMENT.

by the cords A *a*, *ab*, *bc*, *cd* of fig. 2617. Thus to find the radius of the arc of a circle, showing the development of each of these parts of a cone, the chords which answer to the courses of the voussoirs are prolonged until they meet the axis.

The interior surfaces of spherical vaults being circular on the plan, as well as on the section, the moulds for the soffite can only be calculated by approximation, and they also require preparatory surfaces, which are not those on which should be traced the arrises of the joints of the voussoirs.

To form these voussoirs more accurately, commence by cutting a prism which has for base its projection on the plan: from this will result a portion of a hollow cylinder, the surfaces of which will be terminated by the extreme arcs of this projection; thus the voussoir represented by fig. 2617. is comprised in a portion of a hollow cylinder, indicated on the plan by *c'' 5' 5'' c'''*. The profile of the mass of this portion of the cylinder is indicated in the section. It will be found that if the several horizontal lines be traced by a bending rod on the curved surfaces, they will show the exact position of the arrises which pass by these joints. There must then be exactly traced on the straight surfaces the arrises in-

dicated by the angles made with the arcs taken on projection. If, according to these lines and those traced on the two straight joints with the mould *5 b, c 6*, the stone which is without be levelled, using the rule, for the joints *6 c*, *5 b*, and cutting out the convex parts for the arcs *5, 6*, and *b, c* of the profile, the voussoir will be indicated with correctness.

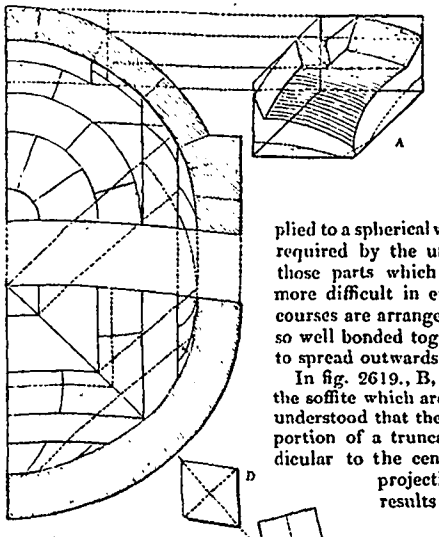


Fig. 2619.

Fig. 2619. represents the section and horizontal projection of a spherical vault, the courses of voussoirs of which form in elevation vertical arches, and on the plans open squares inscribed in each other, like the vault of an arc de cloitre on a square plan; this arrangement presents at the bottom four niches forming together a square.

This is appropriate for niches in straight walls, but objectionable when applied to a spherical vault, on account of the triangular voussoirs required by the union of the four vaulted parts of niches; those parts which rest on acute and fragile angles are more difficult in execution, and less solid, than where the courses are arranged horizontally, because the parts are not so well bonded together, and occasion a thrust which tends to spread outwards.

In fig. 2619., B, C, D, show the moulds for the stones of the soffite which are applicable to this arrangement, it being understood that the surface of each course is formed by a portion of a truncated cone, the axes of which are perpendicular to the centre of the lines, expressing in plan the projection of these slices of a cone; whence it results that each of the hollow squares consists of four parts of similar cones, the axes of which cross in the centre, and meet at the diagonals of these squares. As the direction of these surfaces in a right line is to the summit of each cone, that of the parts which unite on the diagonal tending to two different points should form an angle, which prevents the development of the soffites, corresponding to the angle of a single piece, that is to say, those triangular parts which are at the commencement in the angles.

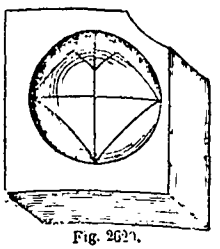


Fig. 2620.

A, fig. 2619., represents the voussoir joining the key in perspective: the joints answering to the lines of the plan, which are vertical, may be traced on the contiguous face of the prism with a square base, in which this voussoir is comprised, with the mould taken from the section.

For the voussoirs of the lower angles a stone must be selected large enough to hollow out a segment of a sphere, capable of containing the soffite of the voussoir, and something more, for the projection, as shown in fig. 2620.; it is then only required to cut out the stone, according to the figure of the soffite traced with curves, and to form the joints with bevels, which give the angles of the soffites, with the sections, and which should all tend to the centre of the sphere: this method consumes more stone, but it is more simple and accurate.

Vaults formed of a portion of an hemisphere, where the Plan is a Square, constructed in Horizontal Courses, agreeing with the preceding examples in every other particular, excepting in the addition of the pendentives; it is the portion of a sphere whose diameter is the diagonal of a square; the parts cut off by the walls form semicircles on their interior surfaces, whose diameter is equal to the inner length of the walls; the section of a sphere by any plane is always a circle.

In the section the arc N I is a portion of a semicircle described with the semi-diagonal C E. The quarter circle A D indicates the re-entering arris formed by the intersection of

one of the walls. The voussoirs are divided on the quarter circle, E N I, prolonged from N to E, representing the section on the diagonal of the vault.

The joints of the stones are only prolonged until they intersect the vertical P E, which indicates the re-entering angles of the walls, prolonged in the part occupied by the vault; those of the pendentives form an arris, also at the intersection of the interior surface of the walls to which they belong. To draw one of these stones, as shown in perspective, for the beds, we use arcs marked on the plan *b b* and *a a*; and for the elevation, those distinguished by similar letters on the section: to form the surface of the stone, instead of a rule a pair of callipers is applied to the great circle, directed perpendicularly to the arcs *a*, *b*.

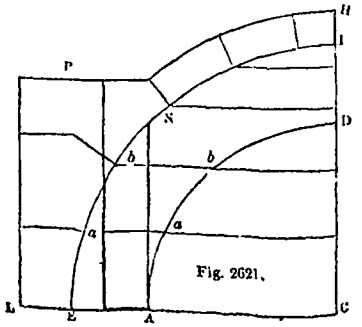


Fig. 2621.

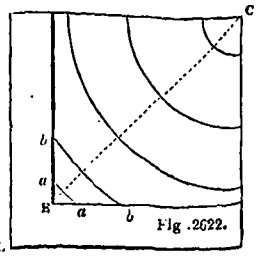


Fig. 2622.

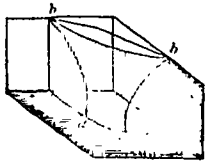


Fig. 2623.
VAULTS FORMED ON THE PORTION OF AN HEMISPHERE.

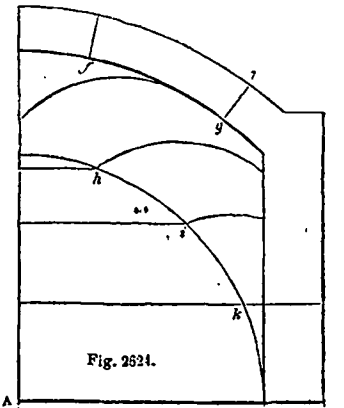


Fig. 2624.

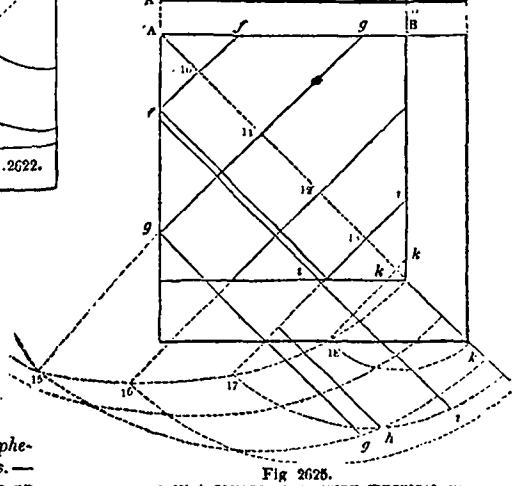


Fig. 2625.
VAULTS ON A SQUARE PLAN, WITH SPHERICAL HEADS LAID IN VERTICAL COURSES.

Vaults on a square Plan, with spherical Heads laid in vertical Courses.— The rows of voussoirs are shown on the plan by right lines, which are drawn perpendicularly to the diagonal; these lines form on the elevation arcs of circles, shown in the section as foreshortened, but developed outside the plan, and having for radii other lines which are the projection lines of the rows of voussoirs prolonged to the great circle passing through the diagonal G E, and expressing the projection of the springing of the entire vault. To draw the voussoirs, we must form a horizontal and perpendicular plane corresponding to the line of projection on the plan; upon it is traced the curve of ele-

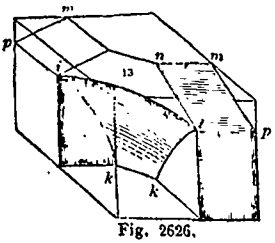
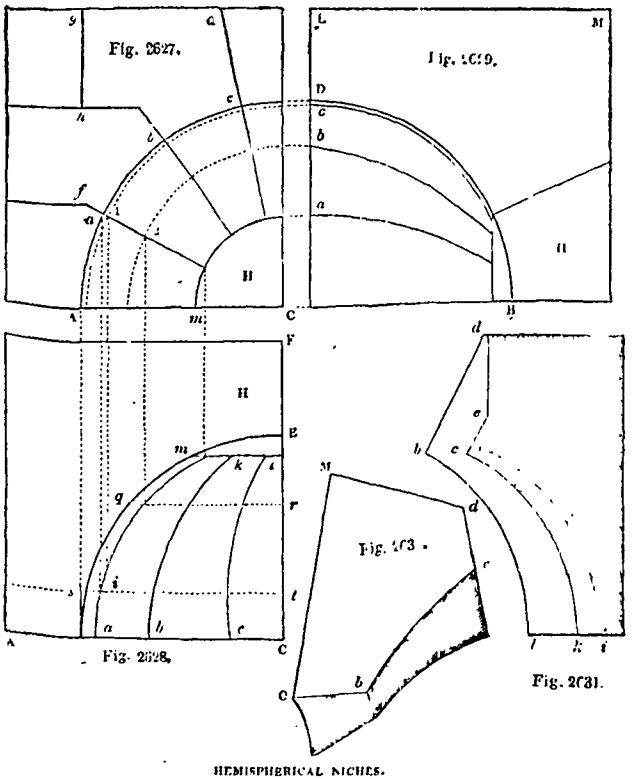


Fig. 2626.

vation, which should form the arris of the section, and the remainder of the operation is performed as in the preceding example, that is to say, with the arcs taken from the section, and on the great circle whose diameter is the diagonal. The voussoir, in perspective is marked with letters corresponding with its position on the plan and elevation. The most convenient method of constructing either entire or segmental spherical vaults is in horizontal courses: we have only described those constructed in vertical courses, to notice the difficulties which they produce, as an assistance to those who prefer some exercise for their ingenuity.

Hemispherical Niches are so formed that they may be cut into two equal parts by a vertical plane passing through the centre, which would support themselves independently of each other, or into four by vertical planes crossing each other at the centre, and each will support itself. Hemispherical niches may be set out by three different methods: by horizontal courses forming half circles or courses; by vertical courses, or in the form of a trompe. The niche has the trompillion, indicated by H; it is shown in front in fig. 2627., on plan, fig. 2628., and profile, fig. 2629. The joints of the voussoir above, tending to the centre of the niche, are indicated by straight lines in fig. 2627., and by curved lines in figs. 2628. and 2629.

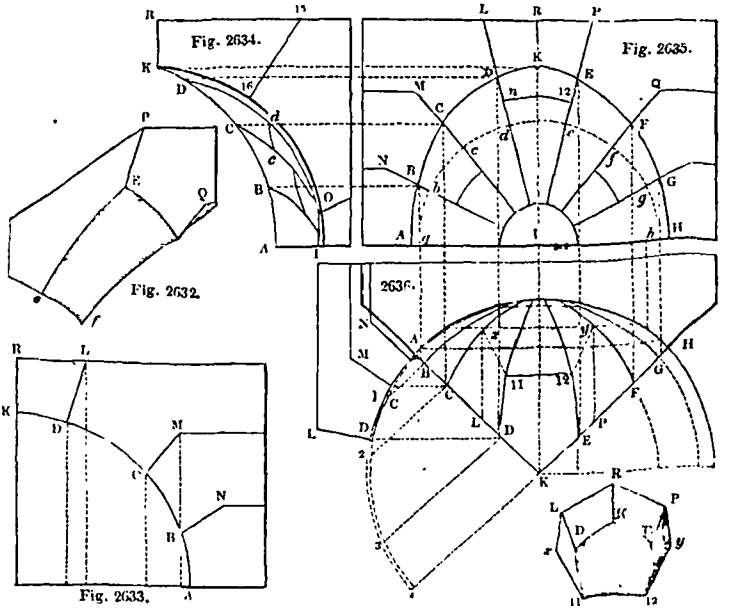
To find the curved projection of these joints, divide the thickness of the wall in fig. 2628., in which they are comprised, into two or three unequal portions, by lines *qr*, *st*, parallel to the face A C; these lines are radii of the quarters of a circle, which divide the surface of the niche in elevation into parts proportionate to those of the plan; thus for the first joint *a i* of the elevation, lower the points 1 and 2, where these quarters of circles cut the joints of the parallels, to the axis D C, common to the two figures; these cut the lines of the plan *qr*, *st*, at the points 1′, 2′, which will be two of those of the projection curve of this joint in plan, and should terminate at the points *a*, *i*, giving four points by which it may be traced, and so on for the others. To trace the voussoirs of this niche, moulds may be used for all the faces and joints, viz. one for the elevation, fig. 2627., which may serve for the two sides by turning it from right to left; two for the joints, and one for the trompillion. The moulds for the joints are shown at fig. 2631., placed one over the other, so that the line indicating the arrises of the returns of the quoins, and the arris of the extrados of the key, are common to all. As the hollow surface of this niche is supposed to be exactly spherical, the curves *cl*, *bk*, *ai*, are equal arcs of circles described with the radius A C. Fig. 2630. represents the key, in perspective; its arrises and principal angles are indicated by letters corresponding in figs. 2627, 2628, and 2629.



HEMISPHERICAL NICHES.

A Niche situated in an Angle. — Figs. 2636. and 2637. show the plan and elevation; the divisions of the voussoirs which tend to the centre I are made on the semicircle *abcdefgh* of the elevation, the projection of which on the plan is shown by a straight line, with

the corresponding divisions marked with the same letters. The divisions on the front centres are determined by prolonging the joints until they meet the vertical planes of the projecting angle; the curved arrises which they form with the soffites are, on account of the property of the sphere, quarters of a circle of which A B C D E F G H in the elevation only indicate that the ellipsis formed with the ordinates B 1, C 2, D 3, K 4, is of a quarter of a circle, of which A K is radius. One of the two faces developed is shown at fig. 2635., with its divisions of joints to serve as moulds. Fig. 2636. shows the section



NICHE SITUATED IN AN ANGLE. Fig. 2637.

taken on the common axis, R I K, of the projection in plan and elevation. As this niche is supposed to be of such dimensions that the voussoirs cannot be made in one single stone, the profile of the joint which divides the key into two parts, and that of the trompillion, is indicated in the part shaded; the lines formed by the joints of the other voussoirs on the concave surface are also indicated in the plan and elevation, and in the part of the profile which is not shaded. The upper part of the key, the profile of which in fig. 2634. is represented by fig. 2637.: to form this part of the voussoir, begin with the upper horizontal bed, which is the largest face, indicated in fig. 2636. by K, L, *x*, *y*, P; after having applied a mould with the same form to trace its contour, cut the two faces L R D K and R K E P square with the upper part; apply to each the mould R L K D, taken on the fig. 2633. on the return, in order that the side R K should fall on the arris K R for the two sides. These moulds, with the angular bevel R L D, will form the surfaces, on which should be applied the moulds of the joints, which will give the curves and arrises of the soffites: according to these curves, and those of the faces D K and K E, formed by tracing with the aid of points on K 16 of the profile, the curved surface of this soffite may be set out, on which having traced the line 11 12 terminate this part of the voussoir by forming the back section with a bevel, producing the angle K 16 15 on fig. 2634.

Fig. 2632. is another portion of the voussoir, uniting with the level courses; this may be traced, like the preceding, by commencing with the upper horizontal bed, for which apply the mould to the plan, make the large joint on the side of the key by means of bevels taken on the elevation; then the facing, and the part of the joint forming a rebate, which should be square with the upper bed; having prepared the face of the other joint, trace with the moulds the straight and curved arrises which are to terminate them: for the soffite, use points taken on the profile, as for the preceding voussoir.

Spheroidal Vaults upon a circular and elliptical Plan. — Fig. 2640. shows one quarter of a spheroidal vault on a circular plan, the half of which is an elevation or half ellipse. Fig. 2639. is divided into three courses of voussoirs to the key; the first, the section of

which is expressed by E, *d a* A G. The curve of the extrados gives at the centre of the key a thickness equal to the

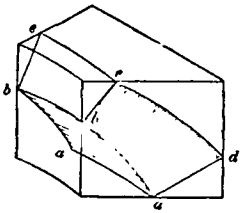


Fig. 2638.

half of what it is where detached from the wall. Fig. 2638. shows in perspective one of the voussoirs of the second course, developed in a portion of the hollow cylinder, the base of which is taken on the plan, where it is marked by the letters *h, i, k, m*, comprehending the projection of the lower section: on the straight joints of this species of prism apply the mould *d a b e* taken on the section, fig. 2639., which must be turned to trace the other side.

Spheroidal Vault on an oval or elliptical Plan, the inner surface of which is produced by the ellipsis or oval of the plan, which turns round its greatest axis or greatest diameter, so that all its vertical sections made in the direction of its length, parallel to the lesser axis, will be semi-circles.

The primitive centre for dividing the voussoirs is the quadrant of a circle, whose radius A C is equal to half the lesser axis of the ellipsis on the plan. The rows of voussoirs being horizontal, the curve of the greater axis being more elongated than that of the lesser, the intradosses are not of equal breadth, but increase from the lesser to the greater axis. The projection on the plan of the horizontal joints form similar ellipses, that is to say, their two axes preserve the same proportion, but they are not equidistant.

The execution of this kind of vault is attended with many difficulties, and requires more operations than that for spherical vaults with a circular base, because, by reason of

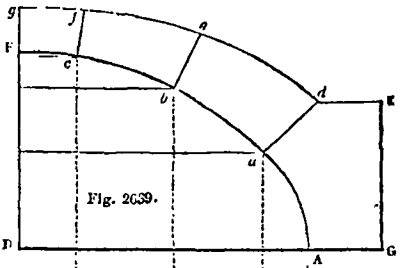


Fig. 2639.

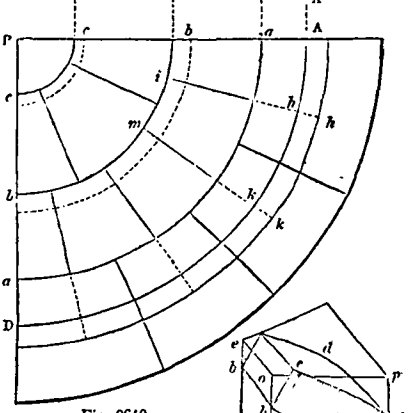
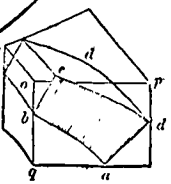
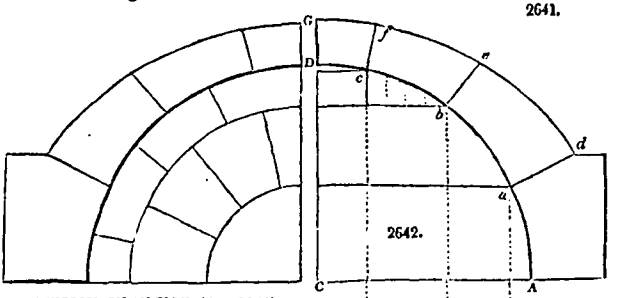


Fig. 2640.

SPHEROIDS ON A CIRCULAR PLAN.



2641.



2642.

SPHEROID ON AN ELLIPTICAL PLAN.

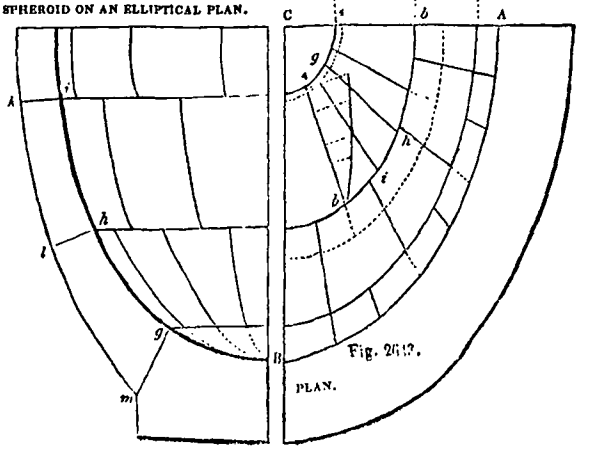


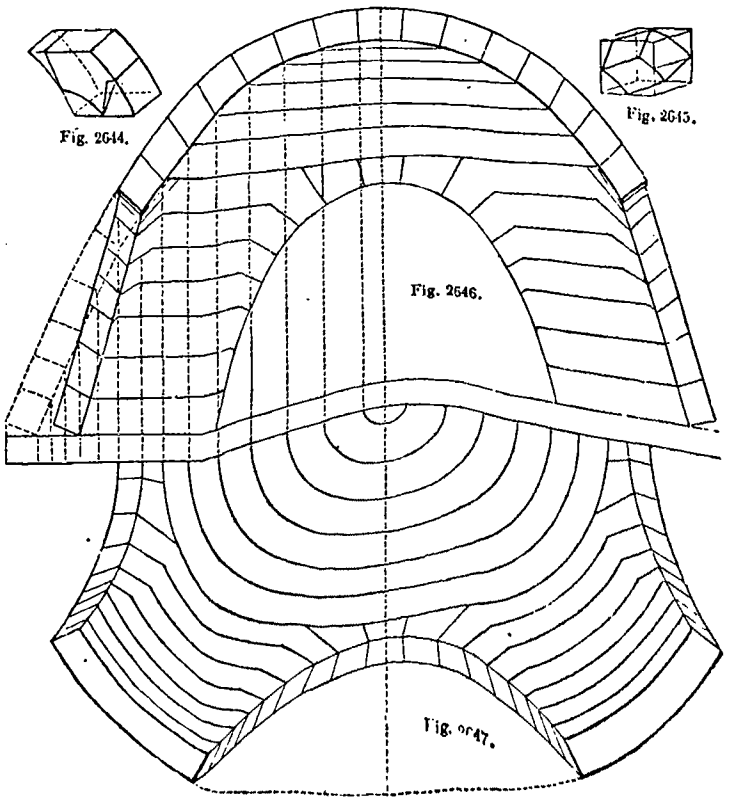
Fig. 2643.

PLAN.

the inequalities of the diameter of the elliptic base, each upright joint requires to be elongated. A simple method of obtaining these elongations, for example, that of the upright joint whose projection is expressed by the right line $b4$ on the plan, is first to let fall from the primitive centre corresponding to this joint, the perpendicular $c4$, and the horizontal $b4$; secondly, after having divided $b4$ into four equal parts, draw through these points lines parallel to $c4$, till they intersect the curve; likewise divide the projection line $b4$, on the plan, into four equal parts, and having raised perpendiculars through these points, set off on each the height corresponding to that on the section, and through all these points draw with a flexible rule the curve bc, which will be that of the joint indicated by the right line $b4$; the curves for the intrados and extrados may be found in a similar manner for each joint. The joints in the thickness da, eb, cf, do not form surfaces of concentric cones, whose summits are in the axis of the vault, as in spheroidal vaults with a circular base, but a doubly curved surface.

A more simple and easy method is represented by the rows of voussoirs shown on the plan by right lines drawn parallel to the lesser axis, and on the section by concentric circles, whose diameters are the corresponding lines on the plan; the joints of these circles form surfaces of truncated cones, whose summit is the point where the joint prolonged would meet the great axis; the other joints will be plane surfaces tending to the axis; by this arrangement we draw the voussoirs, by taking the concentric arcs to form the circular arrisses, and the joint moulds from the section, which will be the same for all the voussoirs of the same row. To form the intrados and extrados, take the convex and concave curves from the section, and divide the joints into the same number of equal parts.

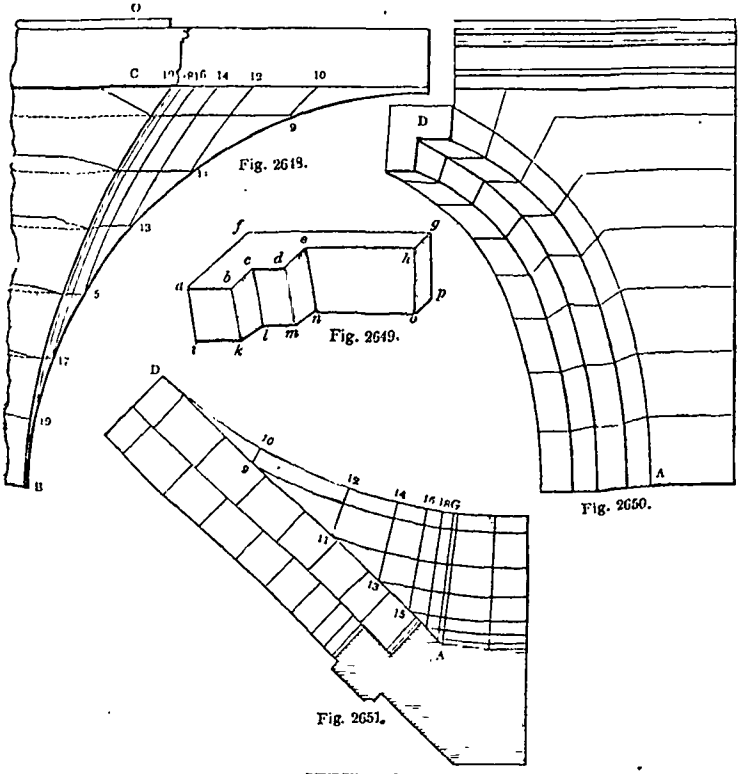
Conoidal Vaults, as in the interior of the Dome of the Panthcon at Paris. — The curve of its centre, as well as that of the open arches, are Catenarian. To execute this kind of vault it is sufficient to have the section and the plan, because each voussoir is cut



CONOIDAL VAULTS.

as before explained for the spherical vaults, forming first the parts of a cylinder in which they are comprised, in order to trace them by means of moulds of the curves taken on the section and plan; the voussoirs, where the open parts or lunettes intersect with the other, should be obtained out of portions of cylinders, comprising their greatest height, length, and width: besides the moulds of the section and plan we must have others of the intrados and extrados, made of flexible material; this method would suit every variety of conoidal vault, whatever be the curve of its centre, hyperbolic, parabolic, or any other, and even whatever the form of base, circular, oval, or elliptic.

Pendentives that support domes are portions either of spherical or spheroidal vaults, resulting from the section of several parts of these vaults by vertical and horizontal planes: they are made use of in gathering over a square or polygonal figure into that of a circle or ellipsis. The domes at the intersection of the naves and transepts of a church are so constructed.



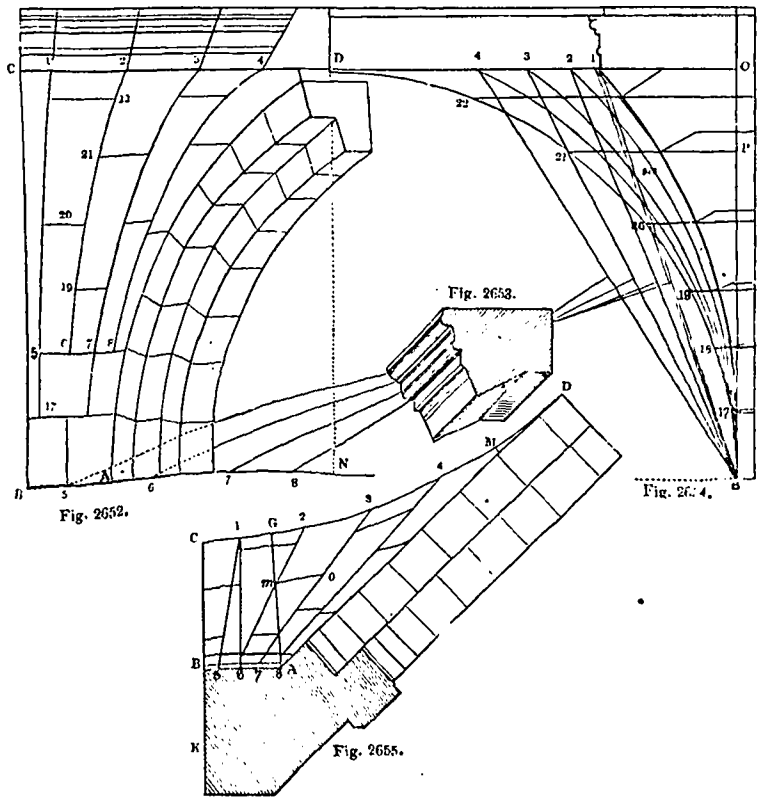
PENDENTIVES.

When the plan upon which the dome is to be placed is square, the faces of the four great arches that are to support it may be considered as four vertical planes cutting a spherical dome into as many segments, and the base of the cupola usually constructed on it, as a fifth horizontal plane which cuts off the upper portion of the sphere, so that four spherical triangles alone remain; but as the effect of these resting on a point is unpleasant to the eye, various arrangements have been made to overcome this defect. The faces of the pendentives are not always portions of spherical vaults, but irregular surfaces, the plan and elevation of which are shown.

Where rows of horizontal voussoirs are introduced, their execution and arrangement will be found extremely simple; the projection of the rows is shown on the plan by lines of concentric circles. To obtain these curves suppose between G and C as many vertical arcs as there are points of each curve; to unite them on the section, so that they have a common point B, set off A G, *abcd*, B C, projections on the plan of these arcs from O to C, *db* G, and draw the chords B G, B *d*, B *b*, B *e*, on the middle of which raise perpendiculars cutting the horizontal line B I in 1, 2, and 3, which will be the centres of each of these arcs.

On the section is shown the position of the various arcs numbered on the plan, which tend to the centre of the sphere, of which the triangle D A G is a portion. The figure in perspective is a voussoir of the fourth bed.

Another method by Voussoirs in the manner already described for the Construction of a Trompe. —The surface of these pendentives are portions of arcs of circles, but instead of being comprised in planes tending to the axis of the dome, they are contained in those which unite in the interior of each pillar, at a vertical line whose projection is the point K: in order that this should produce a good effect, the joints are not divided on the entire arc C D of the plan, but on the part between C and M, to avoid the too great thinness of the edges of the row of voussoirs joining A D; the part M D may be a fourth or fifth of the arc C D; in the present instance it is rather less than the fourth.



PENDENTIVES.

To draw the projection of these joints commence by dividing C M into nine equal parts, one of which is given to half the key, and two to each of the other voussoirs: then having prolonged A D, till it cuts C B prolonged in K, draw through these points to 1, 2, 3, 4, right lines which cut A B in the points 5, 6, 7, 8. The lines 1 5, 2 6, 3 7, 4 8, express the projection of the chords of the arcs which form the upright joints of the voussoirs: by setting off these on the elevation, draw the chords in a similar manner, but neither those on the plan nor on the elevation give their true length, by reason of their double obliquity; to have this, after having drawn the horizontal line C D, raise a perpendicular to it, O B, equal to B C, and set off on C D the distances O 1, O 2, O 3, O 4, O D, equal to B C, 5 1, 6 2, 7 3, 8 4, 8 D on the plan; then draw the lines B C, B 1, B 2, &c. &c., which will be the chords of the arcs required: these centres may be found by raising on the middle of each perpendiculars which will cut B N in 5, 6, 7, and 8, which will be the centres of the arcs corresponding to each of these chords. Then having prolonged the lines 17, 18, 19, &c. &c. from the horizontal joints of each voussoir in the section, in such a manner that they cut the arcs just traced, these intersections will serve to find the projection of the plan of the hori-

zontal joints, by setting off their distance from the line O B on the lines 1 5, 2 6, 3 7, and 4 8, of the plan; thus for the joint P 2 1 of the section set off P *a* on the plan from B to *g*, P *b* from 5 to *i*, P *c* from 6 to *m*, and P *d* from 7 to *o*: through the points *g*, *i*, *m*, *o* draw a curve, which will be the projection of the joints situate on the line P 2 1.

The projection of the plan of these joints and the intersections of those represented by the lines 1 5, 2 6, 3 7, 4 8, furnish an easy method of drawing the foreshortening of the joints on the elevation, by setting off the distances of the intersections from the line B C on the plan on the right lines, which indicate the horizontal joints of this elevation on the vertical B. C The stone in perspective exhibits one cut to suit this arrangement.

Groined Vault over a circular Plan consists of two semicircular vaults, differing in diameter, crossing each other; the principal, A H D E, is comprised between two circular concentric walls, and traversed by an irregular conical vault, I G Q S, whose heights agree.

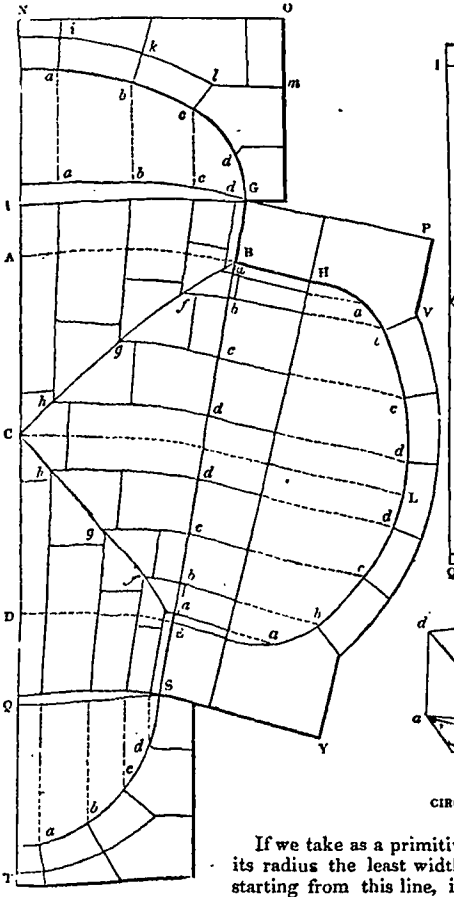


Fig. 2656.

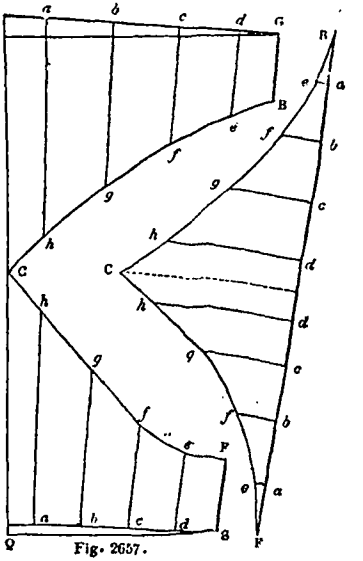


Fig. 2657.

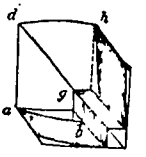


Fig. 2658.

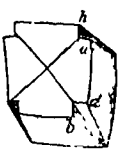


Fig. 2659.

CIRCULAR GROINED VAULT.

If we take as a primitive centre the quadrant M S, having for its radius the least width, Q S, it results that the curvature, starting from this line, is formed by different quarter ellipses, whose greater axes increase from Q S to I G, while the lesser remain the same. The only difficulty in this kind of vault is to form the voussoirs at the arris properly.

After having projected them on the plan, the mould is taken from them, by the assistance of which prisms are cut, having a mixtilinear base; on the faces of this solid moulds are applied, taken from the centres on the sections. To form the hollow parts regularly curved rules are made use of. The development and the voussoirs are also indicated.

Constructions for a Circular Staircase round a newel, called Vis Saint Gilles, first practised at the priory of that name, situated about four leagues from Nismes, has the reputation of being the most difficult operation that could be performed by a mason; all the surfaces of the voussoirs are irregular, and the arrises formed of double curves.

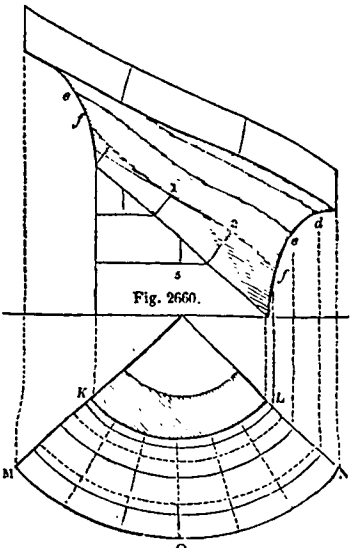


Fig. 2660.

Fig. 2661.

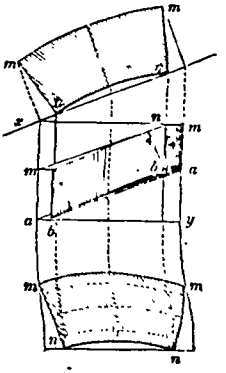


Fig. 2662.

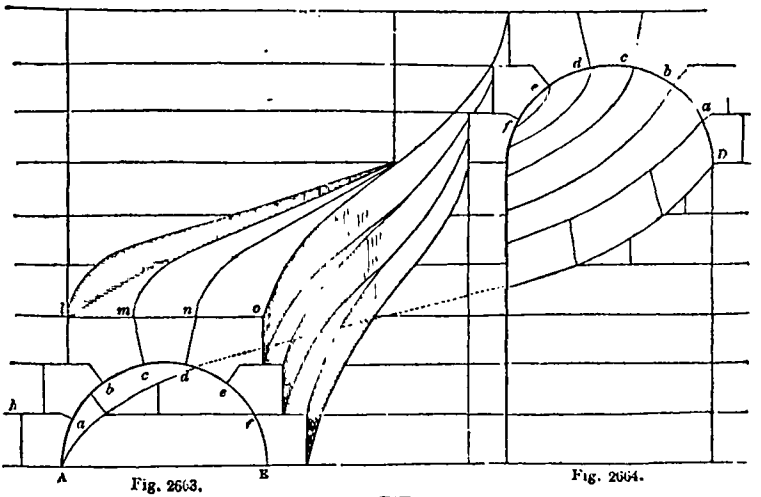


Fig. 2663.

Fig. 2664.

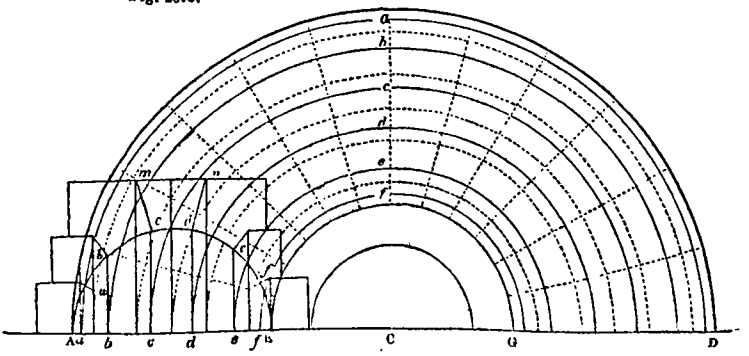


Fig 2665. CIRCULAR STAIRCASE.

The hollow A*abcdef*E is the primitive centre of the vault; the easiest method of constructing such a stair is first to set out that part of the hollow cylinder, *axmy*, in which each voussoir is comprised, according to its projection *mm,nn*, on the plan, in order to trace on their curved surfaces their ramp and arrises, as well as the heights and widths of the steps to which they correspond. In regular staircases like the present, the steps being equally divided, give for the developments of the concentric circles *bdb*, right lines more or less inclined, which may be drawn on the curved surfaces corresponding to them with pliable rules. This operation being performed for the arrises *mm,nn*, of the thickest voussoirs, we may afterwards cut away the rampant part and form the smooth soffite and extrados. To trace the voussoir, apply at each end the mould *medn* of the primitive centre: the curve of the intrados and joints being set out, draw on the intrados two lines parallel to the curved edges of the smooth soffite; then to form these joints cut away the stone beyond the lines, applying the rule always vertically from one curve to the other, and hollow the intrados according to the curves traced at the two ends, by means of compasses, taking care to keep perpendicular to the side on which is the curve; the voussoir is terminated by cutting the two ends *n*3 and *b*4 at right angles to the extrados.

Another method to perform this Operation, and to economise Stone. — Commence by making the horizontal projection *mm,nn*, of the voussoirs X, proposed to be executed, and draw the geometrical elevation in order; to find the section of an oblique cylinder in which it may be comprised, indicated by the lines *mn* and *ba*, representing two parallel planes, which pass through the highest points, *m,n*, and the lowest points, *a,b*, of the voussoir when in its place. To have the inner curve, which produces this section, divide the chord *nn* of the arc, expressed in the horizontal projection, into equal parts, through which draw the ordinates of the curve; then divide the inclined chord *nn* into the same number of equal parts, through which raise other perpendiculars, and set off on each the height of that which corresponds to it in the horizontal plane. This effected for the two curves will give the mould *mmnn*, for the section of the oblique cylinders in which the voussoir should be comprised, and which may be formed with a stone, whose thickness will be equal to the distance between the oblique lines *mm* and *ba*, *pr* and *qs*. This stone should have a face at right angles with the two parallel surfaces, answering to the chord *nn* of the inner curve, for the purpose of tracing from the elevation the vertical lines *nb,nb*, which serve to fix the position of the mould, *mmnn*, with which the contours are traced, to form the oblique section of the cylinder in which the voussoir is comprised: this section being made on the inner and exterior curved surfaces, draw the ramp lines in proportion to their heights 56,*n*7, and the breadths *n*6, 57, of the steps to which they correspond, proceeding as in the preceding method for the ramps, the joints, and the extremities of the voussoirs, which should be perpendicular to the lines of ramp.

Vis Saint Gilles, on a square Plan. — This example is composed of jointed vaults, and skewed as well as rampant *arc de cloitre*; its execution is attended with some difficulty. The centres corresponding to the arrises of the steps, perpendicular to the middle of the faces, can alone be right lines, all the others being oblique, and forming more or less elongated ellipses, according to the steps to which they appertain. The plan of the vault shows one half the arrangement: the primitive centre is a semicircle I K L, raised perpendicular on I L as a diameter; on this semicircle the voussoirs are set out through the points *a,b,c,d,e,f*, through which lines parallel to the faces B C and F G of the wall are drawn, till they intersect the diagonals F B, G C; these lines, which indicate the projections of the rows of voussoirs, would form on the plan of the entire vault squares inscribed in each other, as in the projection of an arc de cloitre; the two halves of the primitive centre are represented on the section, with the thickness of the vault, extradossed in a right line, and in the direction of the steps it is to sustain; this figure is a section of the rampant part of the vault, forming an arc de cloitre along the wall B C, and of the portion returned, C D, with the projection of the joints corresponding to those indicated on the plan by *aa,bb,cc*. Half the section is shown on the side of the newel, forming an arris vault, with the direction of the joints corresponding to *ff,ee,dd*, on the plan. To trace the voussoirs commence by drawing on the plan and elevation the particular voussoir to be executed, in order to form the mould, which comprises its greatest length, breadth, and height; having then cut a prism, whose base is the plan of the voussoir, trace on its vertical surfaces curved or right lines with the moulds taken from the corresponding section.

To draw the rampant vault forming the joint *gh*, divide the arc *ab* of the primitive centres into equal parts, and draw through these points lines cutting *gh*, which may be regarded as the profile of a vertical plane passing through this joint; the intersections give the heights, which, starting from the point *h*, correspond to the projections shown on the plan by parallels drawn from the division points of the primitive arc *ab* on the projection of the same joint, indicated on the plan by *gh*, where this line repre-

sents the projection of the vertical plane forming this joint. To draw the curve corresponding to gh on the plan, set off on the parallels which indicate the projections the

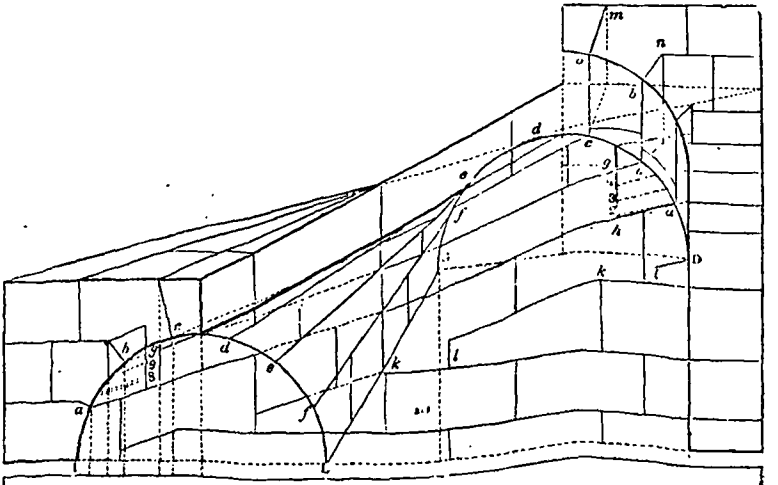


Fig. 2666.

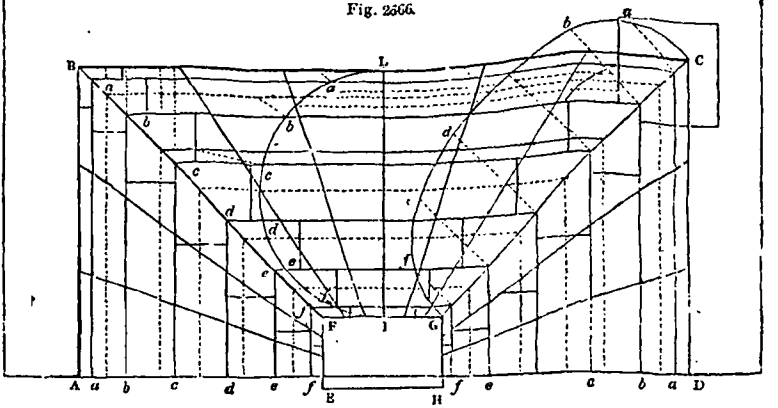


Fig. 2667. VIS SAINT GILLES, ON A SQUARE PLAN.

heights $h3$, hh, and gh, of the joint gh on the elevation from 3 to 3, from 4 to 4, and from g to g on the plan, and draw with a flexible rule through the points $h3$, $4g$, a curve which will express that part of the arc rampant of the joint, indicated by hg on the plan and elevation. The same method is adopted to find the curvature of the other joints: we must observe that those which are perpendicular to the middle of the faces of the walls and of the newel are portions of the primitive centre: the centres on the direction of the steps are half-ellipses, whose lesser semi-axis, indicating the height of the centre, is always the same, while the greater axis, which is level, is represented by a line tending to the centre of which it is a part: these ellipses may easily be drawn by means of foci, serving to form curves for the adjustment, when the vault is completed. The second voussoir in the angle is in horizontal projection, and serves as the mould for the base of the prism from which the voussoir is to be cut: above this plan is the prism, seen at the angles, in which the voussoir is developed by means of the joint moulds B and C, represented fig. 2668.

The horizontal and vertical projections of the key, marked N on the plan, are also shown; the former is the base of the prism in which the key is comprised; on the sides of the upper figure are the joint moulds E and F.

The horizontal and vertical projections of the second voussoir from the newel is marked O on the plan; the lower is the base of the prism from which it is to be cut, and H and I are the mould joints.

As for the joint moulds, shown on the plan and elevation by the right lines g, h, all their breadths and heights are set out on these lines; thus for the second voussoir, M, com-

mence by raising from all the points of the lines pg and gp on the plan perpendiculars, and one from the point b, on which take a point a to represent the lower re-entering angle of this voussoir; having set off above r, and below k, the height of the slope of

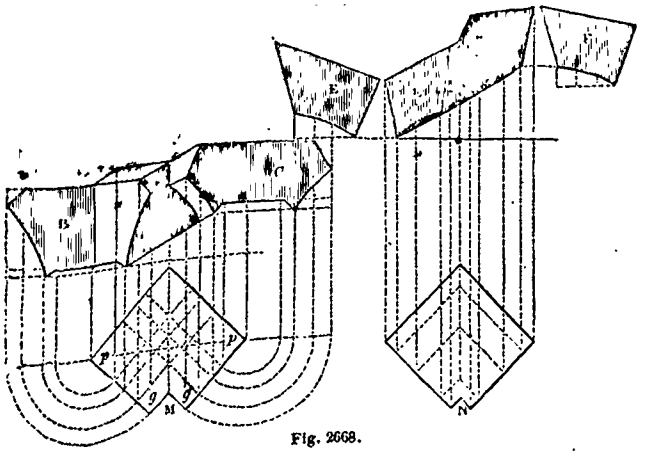


Fig. 2668.

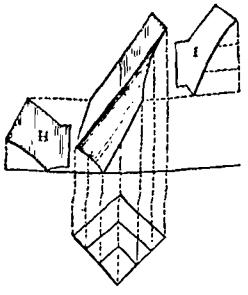


Fig. 2669.

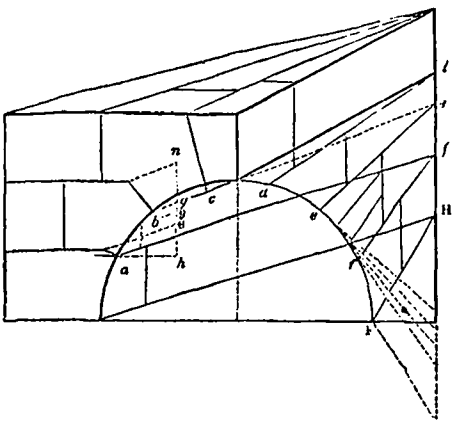


Fig. 2670.

the ascending and descending parts, draw through the two points r and k horizontal lines, which determine the points h and h on the elevation, by their intersection with perpendiculars raised from the corresponding points on the plan: then draw the inclined line $h\,a\,h$, to represent the apparent arris of the lower joints of the voussoir.

To obtain the curvature of the descending branch of this voussoir from the point a, take the heights $h, 2, 3, 4, g, n$, indicated on the perpendicular joint $g\,h$ of the centre; set them off on the perpendiculars raised through the corresponding points of M, beginning from the horizontal line of the base, passing through the point h.

For the ascending branch take the heights on the upright joints g, h of the centre, which will be found similar to those indicated by the letters $h, 8, 9, g, n$ of the section, which were set off in the same manner on the perpendiculars raised on figure M, commencing from the upper horizontal line passing through $r\,h$.

Find the divisions on the perpendicular lines $g\,h$, $g\,h$, which mark the joints, by drawing arrises, $7\,a$, 12, from the profile of the second voussoir, to those corresponding to the upper centre, $2\,a, b\,6$, of the lines which cut the vertical projection of these joints. This operation is founded on the idea that the arrises of the rows of voussoirs on the plan form right lines from the centre of the diagonal B F to that of the diagonal G C. We must observe that the elongated centres of these diagonals are represented on the elevation by semicircles, because the plane of projection on which they are expressed is parallel to the planes of the semicircles from which they originate, and which form the primitive centre of rampant vaults.

Staircase with Quarter Spaces supported by rampant Vaults and Trompes on the Angles, or by the Vault called the Arc de Cloitre. — A B C D is a square plan in which the staircase is placed: commence by drawing the parallels E H, I M, N P, at a distance corresponding with the length to be given to the steps; these lines by intersecting form two squares, A E F N, I K P B, and a rectangle E F K I: it is evident that in the entire plan a square should be formed at each angle, indicating the quarter landings, and four rectangles similar to E F K I for the steps: the well-hole will be expressed by a square or rectangle, F H M K, and N F H C and K M D P will indicate the halves of the ascending and descending ramps.

Fig. 2671.

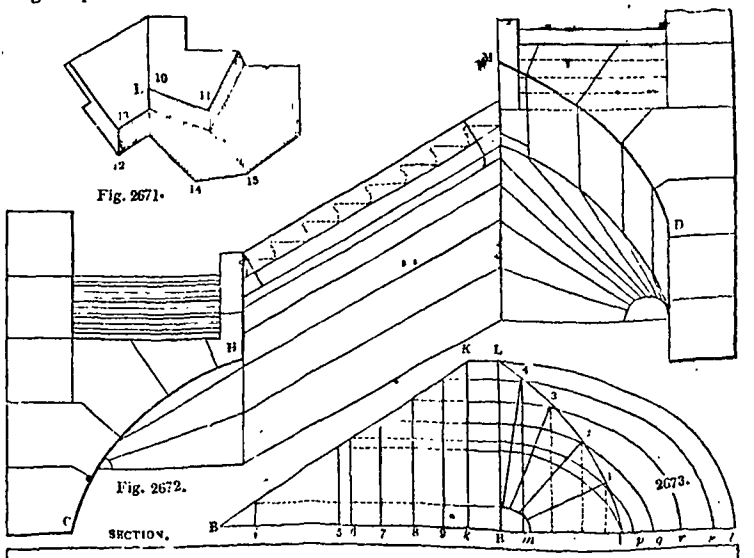


Fig. 2672.

2673.

SECTION.

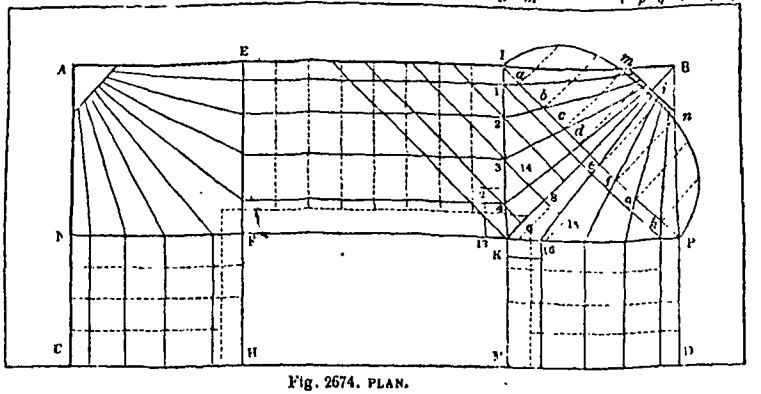


Fig. 2674. PLAN.

To make the projection, having drawn the diagonal I P, and described a semicircle or semi-ellipsis upon it for the primitive centre of the trompe, divide the voussoirs upon it, which set off on the diameter I P, and draw *m n* parallel to I P, to indicate the trompillion; then draw from the point B to all the points of the diameter *a, b, c, d, e, f, h* lines prolonged until they meet the sides K I and K P, which lines will be the projection on the plan of the joints of the trompe.

The cone with a circular or elliptic base which forms this trompe, being cut by two vertical planes K I, K P parallel to its sides, their section is a parabola; and this curve forms the profile of the vault to the right of the lines K I, K P, and not an arc of a circle, as some have supposed.

The figure in perspective shows the voussoir at the junction of the two vaults; after having drawn on the plan and sections to indicate its greatest height and projection, cut prisms, on the faces of which the moulds taken from the sections are applied, showing

the ellipses which pass through the upper extremities of the joints of the trompes, and which determine their elevation; they are drawn by sections described from their foci. The semi-greater axis of each quarter ellipsis is found by drawing on the plan parallels to I P, through the extremities I, 1, 2, 3, 4, and K, of the joints: the semi-lesser axes are obtained by setting off on the section the distances B*i*, B5, B6, B7, B8, B9, B K; from each of these points perpendiculars are raised to the intersections of the line B K, which represents the profile of the cone in its centre, and the height K *k* is made equal to the breadth I K of the ramps.

Another Method, with an Arc de Cloitre under the Quarter Space, whose Springing is level. — The centre of the voussoirs is formed of portions of an ellipsis: to obtain them, describe on N A prolonged an arc of a circle A G, whose semi-chord G N is twice the width of the ramp I H; this semi-chord is divided into seven equal parts, through which ordinates are drawn parallel to N A: having then drawn the lines A N, N G, which form a right angle, both equal to N A, fig. 2677., divide N G into the same number of parts, as N G; and after having drawn parallels to A N, set off the length of the ordinates on fig. 2677., as on fig. 2678., by means of which describe a quarter ellipsis corresponding to the arc G A. The perspective figure is the voussoir I of the section.

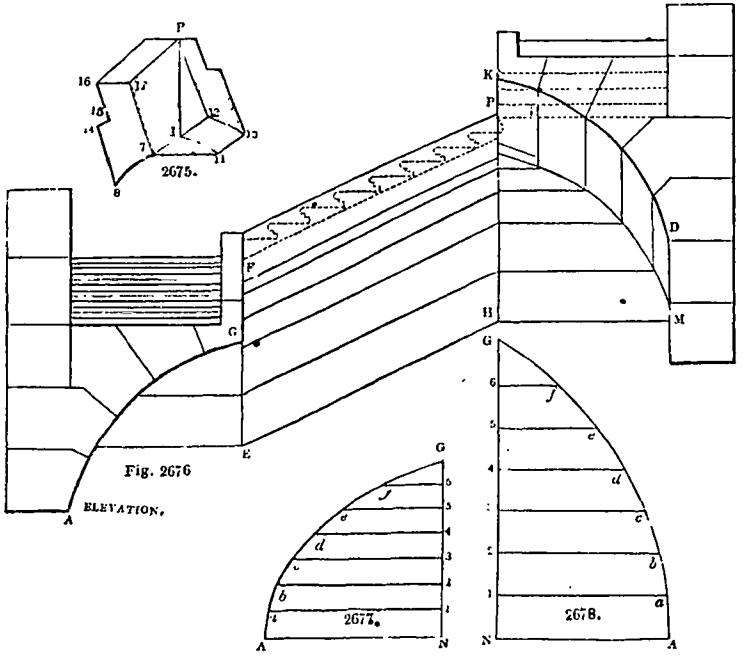


Fig. 2676

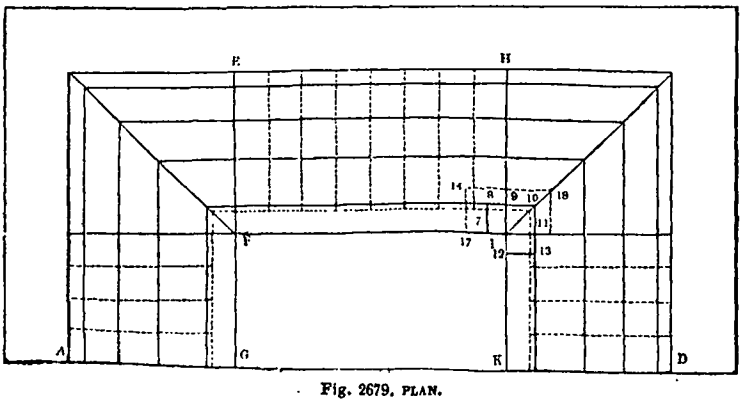
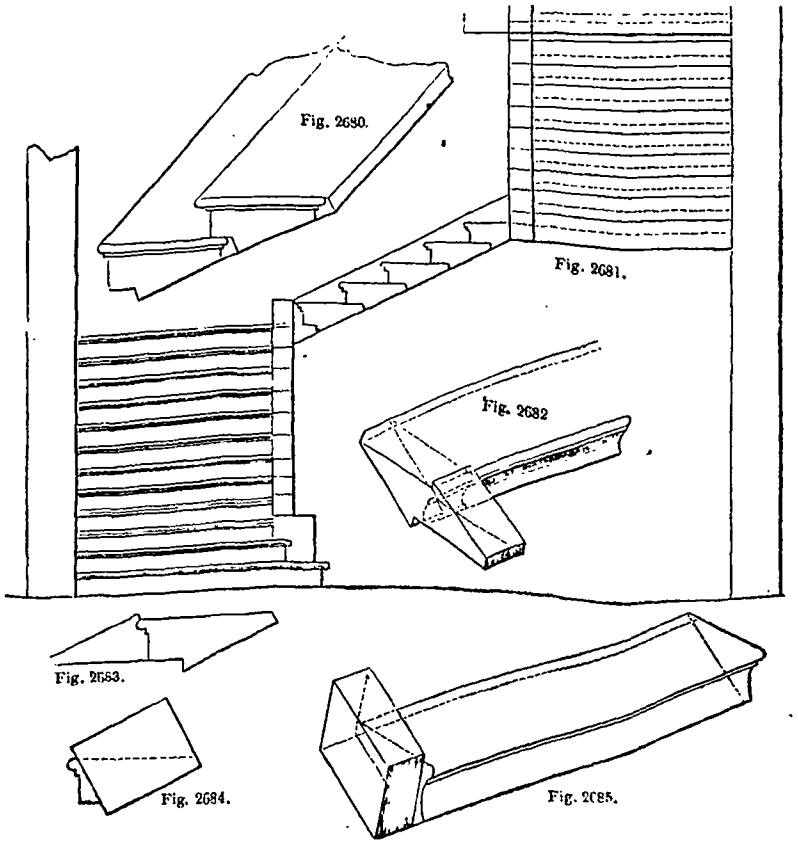


Fig. 2679. PLAN.

An open Staircase, sustained by the steps themselves, without an arch under them, called *geometric*. There are two principal considerations for the construction of one of these staircases, the steps, and the *limon* or string. The steps, which are supported independently of the string, should be formed at their soffites by a smooth uniform ramping surface, terminated at one side by a notch or rebate, *h c d*, and on the other by a face perpendicular to the soffite: by means of these faces, and the steps resting on each other, the stairs are pinned into a wall, and by abutting against the quarter spaces, may be sustained independently of the string. In staircases of this kind, it is necessary to proportion the bearing to the quality of the stone; it is usual to make the section ⅓ or ¼ the height of the step, and the part which bears upon it double; a string at the outer end of the steps prevents the possibility of their turning, when not well pinned at the other end; this is its only advantage, and it is now generally dispensed with: to form the steps, it is only required to have one mould taken from the plan, and another from the elevation.



An example of a similar stairs with winders and quarter space may be constructed either with or without a string on the outer edge; those with a string, as in the former example, form portions of cylinders, on the faces of which, by means of the height and breadth of the steps, the ramps are set out. After having drawn on the elevations, taken from the horizontal projections, parallel lines A B, C D, to indicate the oblique sections of the cylinder in which the portions of the curved strings are comprised, form the elongated moulds from the projections, fig. 2687. and 2691., by raising from all the points *h, b, o, s, p*, of these projections perpendiculars till they meet the line *b m*, parallel to A B, then draw through these points other perpendiculars, on which set off the distances or corresponding widths, taken from fig. 2687. and 2691.; the moulds being found, select a stone whose thickness is equal to the distance comprised between the parallels, and after having dressed these two surfaces, and a face at right angles to them, fix the angle

$b\,m$ of the mould, and trace its contour for the cylindrical section in which the string is comprised: the upper and lower arrises are drawn by means of plumb-lines, and a level

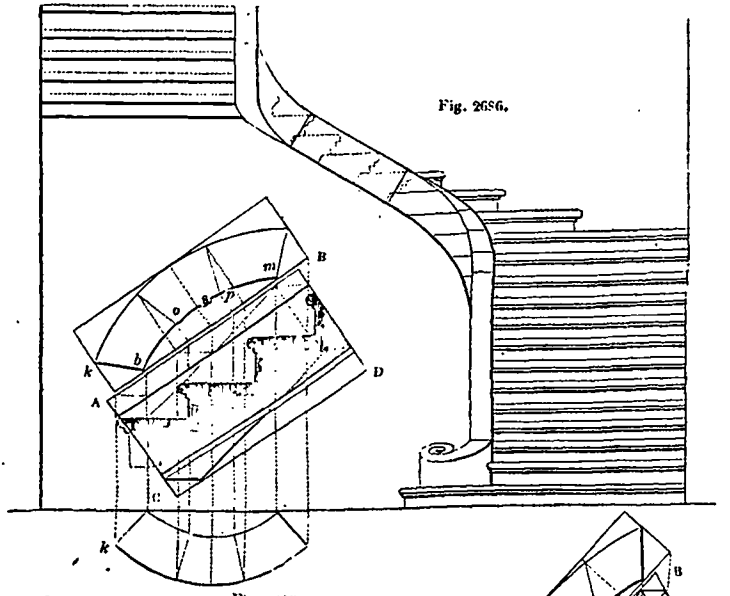


Fig. 2687.

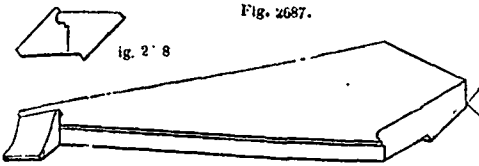


Fig. 2689

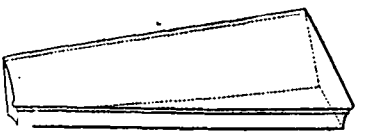


Fig. 2690.

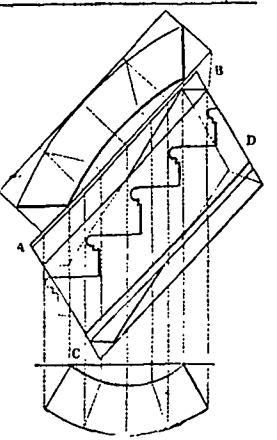


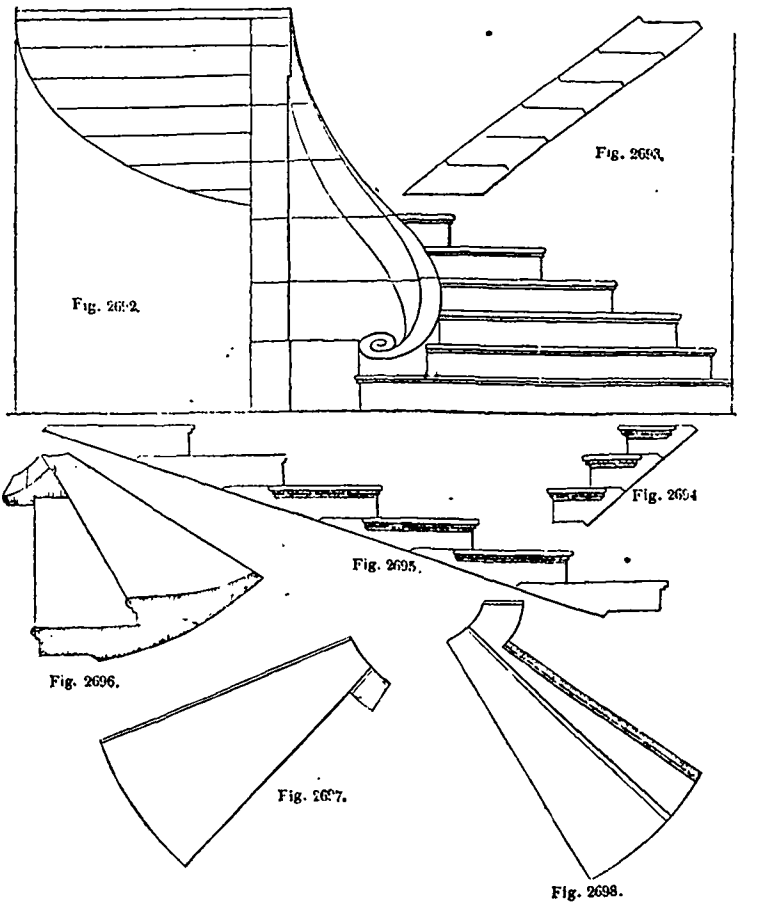
Fig. 2691.

corresponding with the section of the steps at fig. 2687. and 2691. The string is sunk to receive the ends of the steps within it.

Geometrical staircases are now usually formed without a string, each step being partly supported by tightly wedging its end into the wall, and it is further assisted by resting upon the step below it. The outward end of such steps have the nosing returned on them: the under joint, where two steps unite, is made perpendicular to the soffite of the staircase, and the depth of the step, perpendicularly through the middle, must depend upon the quality of the stone; when of a hard quality, like the Cragleith, the following equation may be applied. Suppose w = the greatest uniform load on a square foot, including the weight of the stone itself = 300 pounds: the length of the flight of stairs, measured on its soffite, and which we will call C D = 10 feet, and the length of the step 6 feet, represented by B D; then, $\frac{w \times \mathrm{C\,D^3} \times \mathrm{D\,B^2}}{f(\mathrm{C\,D^2} + \mathrm{D\,B^2})} = d^2$ or $\sqrt{\frac{300 \times 100 \times 36}{26000 \times (100+36)}} = .55$ feet will be the depth of the step, from the middle of the tread to the soffite, in a perpendicular direction. Where the step is inserted in the wall, from 4 inches to 8 may be the depth of the indent; but this must depend upon the length the steps project from the face: in staircases where there are windows, considerable care is required to work the soffite in a regular and easy

manner; and all abrupt changes from one form to another should be guarded against, as they produce an unsightly and disagreeable effect.

Staircase of the same Construction, on a circular Plan, may be executed either with



or without a string at the outer end of the steps: the forms of the steps and their construction are sufficiently indicated by the figures which accompany.

CHAP. XXV.

ON STONE BRIDGES.

HAVING already described several bridges, we shall now proceed to give some account of the theory and practice by which the engineer has been enabled to erect those useful, and, in some instances, magnificent structures, which rank among the greatest efforts of his science and skill.

On the Situation of Bridges. — This must depend on local circumstances, as the leading streets in a city, or the direction of the public roads; but wherever possible, it should be selected at the point where the width of the river is contracted below, and continues in a straight course for a considerable distance below, and its position should be at right angles with the river. Skew bridges, on account of the difficulties attending their construction, should be avoided as much as possible.

The quantity of Water-way to be given may be determined by the condition of other bridges, both above or below the situation of that to be constructed, taking care to make the measurement at the time of the highest and lowest state of the river, and to observe the force and rapidity with which it moves.

The Number and Span of the Arches must depend upon these circumstances, as well as upon the nature of the foundations, the height of the banks, and the material to be employed in their construction.

The greater portion of the following observations on the construction of bridges is selected from the "*Traité de la Construction des Ponts, par M. Gauthey*," as edited by M Naviers, a work deservedly celebrated throughout Europe for its research and practical utility.

To estimate the Quantity of Water to which the Bridge must allow a Passage. — This is not the same at all seasons; not only is it generally less considerable in summer than in winter, but all rivers are subject to temporary increase, produced by abundant rains, or the thawing of snow or ice; and the span of a bridge should be wide enough to allow the mean quantity which the bed contains to flow through, and also afford room for the superabundant quantity arising from floods: it will be found that this quantity of water bears some proportion to the surface of the land which is drained off at that point of the course of the river where the bridge is to be erected; and it is very important to observe carefully the time which the superabundant quantity of water takes to flow through, or its velocity.

Gauthey's Instrument for measuring the Velocity of running Water, consists of a pallet 6·3 inches wide and 3·1 inches high, made of tin plates; a rod 3 feet 3·3 inches long is attached, flattened at its lower extremity, as well as at its upper, but in opposite directions, and having a round hole, $\frac{1}{8}$ of an inch in diameter, through its centre: two holes are bored in the upper part, one oblong, the other circular, $\frac{1}{10}$ of an inch above the first; the whole is so constructed that the rod is in equilibrio about the centre hole. The second part of this instrument is an iron handle about 2 feet 3 inches long, whose lower end is split and pierced so as to clasp the rod of the pallet about the middle, nearly in the same manner as the beam of a balance, by means of a gudgeon turning freely: to the upper extremity of this handle an arc of a circle is attached, having the lower gudgeon for its centre, also a brass wire, likewise curved in the arc of a circle. These arcs should be placed opposite the holes in the extremity of the pallet-rod, and pass freely therein: this flat arc is graduated, to show the different degrees of pressure acting on the pallet; to retain this latter, a spring is secured to the lower end of the handle, and it is attached to the pallet-rod a little below the hole of the arc, by means of a movable ring in the third hole of the rod. To graduate the arc a table of impacts compared to velocities must be formed, in which the first column indicates the current's velocity per second, and the other the impact produced by this velocity. The pallet-rod is then placed horizontally, the handle being firmly fixed; a light bag is fixed to the centre of the pallet, and all the weights shown in the table are successively placed in it, and the spots on the arc where the pallet-rod becomes stationary is carefully marked and engraved.

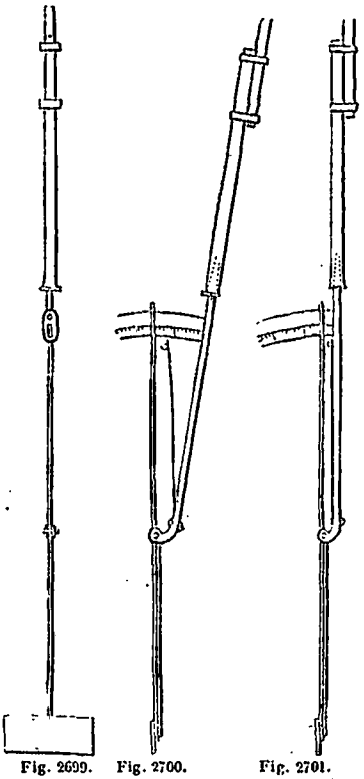


Fig. 2699. Fig. 2700. Fig. 2701.

To use this instrument a small piece of wood is placed in the arc of brass; the upper extremity of the handle is held by one hand, and the lower part of the rod by the other: the pallet is then placed in a current of river water, and the rod allowed to leave the hand by degrees, inclining the handle, so that the pallet-rod is always vertical. The current by its pressure compresses the spring, and advances the small piece of cloth; it is then taken out of the water, and, by pressing the rod till it touches the cloth, the degree to which the spring was compressed may be read off, and hence the velocity of the current: this instru-

ment will measure a velocity of 6 feet 4 inches in a second; but great velocities are too much for the instrument, and very slight are not sensible enough to be perceived; but in rapid currents the pallet may be reduced, and in slow, enlarged; the same graduation will then serve. We know that this velocity depends in a great measure on the fall, and as this commonly diminishes in proportion to its distance from the source, it follows that the same mass of water which would flow very rapidly amidst the mountains where the river takes its rise, and where it is only a torrent, would flow considerably diminished in velocity as it approached near the sea, or the channel into which it emptied itself: thus, admitting that it receives no considerable increase, and that the bed has always an equal consistency, if two bridges were to be constructed over the same river, the greatest span must be given to that nearest the source, although a passage is to be afforded to the same flood, but which will flow through the first in two days, whilst it will take eight to flow through the second. To value the quantity of water, we must multiply the surface of the section by the mean velocity: the first of these two elements of the calculation it is easy to ascertain, but not so with the second, which must be deduced by more or less approximation from the measure of the velocity of the threads of water of which the river is composed, and particularly from those at the surface and middle of the current.

Dubuat, in his experiments upon the motion of fluids, had for his object the determining the relations between the velocity of the surface and that at the bottom of the river, as well as to discover its mean velocity. He also deduced from his observations the following formula: calling V the velocity of the surface, and U the mean velocity, he found,

$$U=(V^{\frac{1}{2}}-\tfrac{1}{2}W)^2+\tfrac{1}{4}W,$$

W being a constant number =0·02707 metres: and to express the relation between the velocity of the surface and that of the bottom, calling this last W, we have

$$W=(V^{\frac{1}{2}}-W)^2$$

On these two formulæ he calculated a table, which gives the value of the velocities of the bottom and the mean velocity, relatively to that of the surface, from V=0·027 metres to V=2·707 metres.

On this subject M. Prony has remarked that the above formulæ do not correspond with experience, for supposing the second V=o, we have W=w, whence it follows that the velocity of the surface being null, that of the bottom would be equal to 0·027 metres, a result which could not be admitted. If in the first formula, we make V=o, we must deduct for U a finite value, which does not agree with what we find in nature: the relation established between U and V must necessarily give at the same time U=o and V=o, or U= ∞ and V= ∞. M. Prony therefore adopted another equation, $U=\frac{V(V+a)}{V+b}$; and the value of the constant numbers a and b having been determined, after seventeen experiments by Dubuat upon the values of AV, which varied from V=0·15 metres to V=1·80 metres: he found also $a=2{\cdot}37187$, and $b=3{\cdot}15312$, the metre being the unit of the measure, which gives for the preceding formula

$$U=\frac{V(V+2\,37187)}{V+3{\cdot}15312}$$

This formula has the advantage of representing more faithfully than that of Dubuat the results of his own experiments, and of agreeing likewise with the phenomena in question, confined within their proper limits. M. de Prony remarks that from V=o to V=3 metres the relation $\frac{V+2{\cdot}37187}{V+3{\cdot}15312}$ is evidently equal to 0·82, and as practical cases are commonly within these limits, this formula will be sufficiently exact:

$$U=0{\cdot}82\ V, \text{ or even } U=\tfrac{4}{5}V.$$

Neither practice nor theory has hitherto afforded any closer method of deducing the value of the mean velocity of a current of water from that at the surface and middle; but some observations may be made upon the manner of applying the results just explained. The experiments of Dubuat were made in artificial canals, in which the section was a rectangle or trapezium, and where the depth of the water varied from 54 millimetres to 27 centimetres: some reservations must therefore be made in considering the results deduced, and the nature of the motions of fluids is not yet sufficiently well-known to allow of an absolute decision, by comparing great things with small: moreover, the experiments upon which the preceding formula is established have appeared to indicate that the relations existing between the three velocities, V, U, and W, are independent of the size and figure of the bed of the river, and these relations did not appear to change sensibly when the breadth of the bed was six or seven times greater than the depth. "It is thus," observes M. de Prony, "difficult to persuade oneself that the different elements have no

influence on the relative values of V, U, and W: and experiments made on a larger scale would possibly prove that too much deduction has already been made.

In the sixth volume of the Memoirs of the Academy of Sciences are some researches on the motion of fluids, applied principally to what is called linear motion, that is to say, to the case in which the molecules of the fluid move in a rectilinear bed, following right lines parallel to the axis of this bed; and the results relative to the question now under consideration are, that, whatever be the figure of the transverse section, the mean and greatest velocities at the surface and middle of the current tend to become equal as the dimensions of the bed decrease: the relation between these two velocities is independent of their absolute value: if in a rectangular bed the horizontal breadth be supposed very great, and the vertical depth of the water very small, the mean velocity will be about 0·64 of the greatest velocity. If the two dimensions of the rectangular bed are supposed to be very large, the relation between them will be about 0·41, which formulæ give the means of calculating the relation for different beds, of which the transverse sections are semicircles or rectangles.

Experience proves that the true laws of the motion of waters in the beds of rivers or in pipes differ from those of the linear motion: the only case in which nature realises these latter laws is that in which fluids flow in rectilinear pipes of very small dimensions, and the results deduced immediately from this observation are those alone to which we can pay any consideration in the case before us.

At the time of great floods, which is that for taking the elements of a calculation on the quantity of water, it is generally overflowing the banks and extending on both sides over a large surface, where it flows slowly, whilst there is a considerable velocity in the midst of the current, and it is very probable that gross errors would occur if the rules for calculation just cited were applied to these cases. If possible, a part of the river should be selected where the water is so confined that during floods it does not overflow to any great extent; and the section of the velocity should be taken at a bridge, if any exist near the site of that projected.

It must be acknowledged that the means we at present possess for obtaining the direct value of the mean velocity of a river are very limited, and subject to more or less error. As a certain relation must exist between the section, the fall, and the velocity of the current, and as it is always possible to measure these, the value of the velocity would naturally be deduced from it, if its relation were well known; M. de Prony in the work before cited has deduced it from the best experiments he could collect, and has arrived at the equation,

$$U = -0{\cdot}0719 + \sqrt{0{\cdot}005163 + 3232{\cdot}96\,R\,I},$$

in which U being always the mean velocity of the current, R represents the mean radius, that is to say, the area of the section divided by the part of the perimeter of that section which belongs to the solid side in which the fluid flows, and I, the fall in a metre.

Since the researches of M. de Prony, M. Eytelwein has published in the memoirs of the Academy of Berlin some experiments, on the means by which he has established a formula similar to the preceding, but of which the coefficients have somewhat different values: this formula, taking the metre for the linear unity, is,

$$U = -{\cdot}003319 + \sqrt{0{\cdot}0011016 + 2735{\cdot}66\,R\,I}.$$

The experiments which have determined the coefficients comprise the values from two to three metres for the velocity, whilst the experiments which M. de Prony has made do not exceed 0 m. 88 c.. the formula of M. de Prony agrees, as well as that of M. Eytelwein, with experience, as regards small velocities, but they appear to give very feeble results for large ones. M. de Prony has given for the motion of water in pipes this expression,

$$U = -0{\cdot}02488 + \sqrt{0{\cdot}0006192 + 2871{\cdot}43\,R\,I},$$

which agrees better than that mentioned above with those experiments in which the value of the velocity is above one metre. The first equation will give the value of the mean velocity with sufficient practical exactness; but it must be observed, that it supposes the size of the section of the river, and the value of the fall, to be the same in a sufficient length for the mean velocity to be regarded as constant; and it is necessary to take this into consideration when the formula is used.

The dimensions of the beds of rivers are generally sufficiently constant, with the exception of particular cases in which their course is through sandy lands, which yield with so much facility to the action of water that the current may at each increase be carried into different parts: at each point of the course of the river a certain equilibrium is established between the action exercised by the waters on the cavities, and the tenacities of the matters of which the bed is composed; and in virtue of this equilibrium remarkable changes seldom occur either in the size or form of the bed, which nearly always preserves the same rule. But if, from any cause whatever, the force with which the water tends to corrode and destroy the bottom and shores of its bed be augmented, the bed will be enlarged until a new equilibrium is established, unless the side walls are so composed

as to present a resistance more considerable than the force with which they are attacked. If the rapidity of the river has, on the contrary, undergone a diminution, the bed will increase from the effect of the successive deposits, until the size of the section becomes equal to what had been taken away, according to the relation marked out by nature for the stability of rivers.

It results from these principles, that if the width of the river be diminished by works going on in its bed, the rapidity being increased, a shoal or island will be formed, and such a fall that the bed will be deepened until the increase of the section combined with that of the velocity will compensate for the diminution in the width of the river, and the velocity be again in equilibrio with the resistance of the bottom. If, on the contrary, the width of the bed be augmented, the rapidity being diminished, it will have a tendency to fill up.

It is very essential in constructing a bridge to pay attention to the velocity with which the water will move under the arches, and which must not be allowed so to augment as to force the current to attack the bed of the river and injure the foundations of the piers and abutments; it must not either be sensibly diminished, because in that case a considerable additional length would be required for the bridge, and the deposits which would take place might become dangerous. The nature of the ground of which the bottom of the river is composed must be considered: if excessively compact and tenacious, and approaching to rock, it will not yield sensibly to the action of the water, and whatever then may be its velocity, there is nothing to fear for the safety of the bridge; but as the waters cannot acquire a great velocity, an eddy more or less considerable will be formed above the bridge, which, in the case of the mouth being extremely narrow, might produce inundations in the upper part of the river, and render the navigation difficult. If the bottom be composed of matter which can easily be acted on by the water, care must be taken to prevent the usual velocity from being sensibly augmented: if the ground yield to the action with such a facility that there is reason to fear the increase of the current will be carried under some arches and hollow out the bottom, whilst it would deposit, at the same time, sand under others; this would be a case for constructing a general framework of ground timber, by which the bottom, presenting uniformly the same resistance to the action of the current, would oblige it to distribute itself equally through the whole width of the river; and so long as this framework should subsist, there would be no reason to fear that any of the piers would be injured. From the preceding observations it is evident, that the velocity with which the water will flow under the bridge should be in all cases determined before-hand, either from the nature of the ground which composes the bed of the river, or by the height of the eddy formed above bridge, and which depends on the value of the velocity; and as the quantity of water which the river discharges is also known, the surface of water-way which the bridge should leave can be easily established. The question then resolves itself into the following problem: the section of the bed of the river, and the velocity of the water being given, to determine the new velocity which the current will take, and the height of the eddy which will be formed, supposing that the bed is narrowed by the construction of the piers and abutments of a bridge. This problem cannot be very rigorously solved, but we shall, neglecting some circumstances, the effects of which are not very sensible, and which compensate for themselves in a great degree, give after Dubuat an approximate solution, which can be usefully applied.

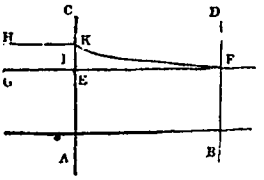


Fig. 2702.

Let us suppose A C, D B to represent the lateral face of a pier, and G E F the natural inclination or fall of the river before the bridge is constructed; the current being confined in the interval E F, the velocity, and consequently the fall, will be there more considerable; and the surface of the water, making allowance for the particular resistances produced by the starlings, will take an inclination represented by the line I F; the surface above bridge will necessarily rise above the point I, represented by the line H K, which for a small length is horizontal.

Let us call Ω the area of the section natural to the river;

ω, the area of the section after the bridge is constructed, or the area of the surface of the water-way;

V, the medium velocity of the river;

v, the mean velocity of the water under the arches, after the construction of the bridge;

I, the fall by metre of the river;

s, the length of the piers and abutments = A B, or E F;

H, the height of the eddy = E K;

g, the accelerated force of the weight = 9·809 metres.

We shall have $v = \frac{\Omega}{\omega} V$, since in a river the velocities are in an inverse ratio to the area

of the corresponding sections, and the heights due to the rapidities V and v will be represented by

$$\frac{V^2}{2g}, \text{ and } \frac{\Omega^2 V^2}{\omega^2 2g}.$$

The part IK of the height of the eddy corresponding to the increase of the rapidity will be then

$$IK = \frac{V^2}{2g}\left(\frac{\Omega^2}{\omega^2} - 1\right);$$

and as, on account of the contraction which the current will undergo in general at the passage of the bridge, the section ω is diminished, we must substitute in this expression the area ω by $m\omega$, designating by m a coefficient, the value of which depends principally on the width of the piers, as well as the form of the starlings and springing of the arches. We shall have then

$$IK = \frac{V^2}{2g}\left(\frac{\Omega^2}{m^2\omega^2} - 1\right).$$

We must now seek the value of the fall, which will form itself on the length of the piers: before the construction of the bridge this fall was equal to sI; and as the falls increase nearly in the relation of the heights due to the correspondent velocities, we shall have for the value of the new fall,

$$sI\frac{\Omega^2}{m^2\omega^2}.$$

Thus the part of the height of the eddy which arises from the increase of the fall under the arches of the bridge will be represented by

$$EI = sI\left(\frac{\Omega^2}{m^2\omega^2} - 1\right);$$

and we shall have

$$EI + IK = H = \left(\frac{V^2}{2g} + sI\right)\left(\frac{\Omega^2}{m^2\omega^2} - 1\right)$$

for the height to which the waters of the river rise above bridge, since their level must remain the same below bridge. To apply this result it will be sufficient to put in the place of V the expression $v\frac{m\omega}{\Omega}$, and to give afterwards to v the value which will have been fixed before, according to the principles referred to, for the velocity which the waters take under the bridge. As to the value of the coefficient m, we are unable to fix it very exactly; the experiments relative to this subject have been made on orifices pierced in walls of different thicknesses, to which pipes have sometimes been adapted, and through which the water flowed under weights more or less considerable; independently of the circumstance that the dimensions of these orifices, even in experiments made on the greatest scale, are not to be compared with those of the arches of bridges, it must be remembered that the flowing is different from that now under consideration.

The form given to the starlings of the piers of bridges has a sensible influence, as well as the thickness of the piers, on the manner in which the contraction operates, by which the natural flow of the river is modified on meeting the bridge. The value of the coefficient m, as we have seen, depends principally on the form of the starlings and the springing of the arches, when they are plunged in the water. We have not fixed with exactness that which it would take in different cases; but we should not be far from the truth in supposing $m = 0{\cdot}95$, when the piers are terminated in a half circle, or by acute angles; $m = 0{\cdot}90$, when terminated by obtuse angles; $m = {\cdot}85$, when terminated square, supposing the arches to be large: in the most disadvantageous cases, that is to say, for small arches, and when their springing is under water, the value of the coefficient m may be about 0·7. In putting in the preceding equation for H and v the values which we have given, according to the nature of the bed and other local circumstances, we shall easily deduce from it that of the relations of the two sections ω and Ω.

To determine the height of the eddy which may be formed above bridge, we must consider the changes it will occasion in the height of the river, and the inundations which may hence result on the banks. According to Dubuat, it is generally admitted that the surface of the waters, which, before the construction of the bridge and in the hypothesis of a uniform fall, was an inclined plane, becomes after the construction a concave surface, touching the primitive surface at the point where the exhaustion of the water ceases. This author has also given rules for the calculation of the eddy, on the supposition of the profile of this surface being the arc of a circle of great amplitude; but much confidence cannot be placed in them. When the bed of a river is irregular, and presents considerable variations in the fall and in the width,—when, in the case of an

increase, a part of the waters flow slowly over inundated banks, the exact figure of the surface of the fluid cannot be obtained, but it may by a sufficient approximation when the bed is uniform and the movement of the waters permanently established. M. Belanger, engineer of the *Ponts et Chaussées*, has given for this purpose the following calculation:—Let us call s a length taken on the bottom of the bed, in the direction of the stream; h, the vertical height of the transverse section of the current; w, the area of this section corresponding to the height h; x, the width of the section w taken on the surface of the water; R, the mean radius; i, the fall of the bottom of the bed in metres, which is supposed to be constant; Q, the volume of water which the river discharges in a second; we have the equation

$$s = \int dh \, \frac{\frac{Q^2 x}{g\omega^3} - 1}{\frac{1}{R}\left(0{\cdot}00002427\frac{Q}{\omega} + 0{\cdot}0003655\frac{Q^2}{\omega^2}\right) - i}$$

in which the metre and the second sexagesimal are taken as units of length and time, g representing the velocity 9·809 metres, which the gravity may impress on the body in a second; all the quantities comprised under the sign $\int$ may be valued as the function of the height h of the section. In calculating the value of the integral indicated by this sign, setting off from the greatest value of h, which takes place at the point of elevation, that is to say, immediately above bridge, to a second value intermediate between the preceding and natural value of the section, the result will give the length comprised between above bridge and the section to which belongs this second value of h. We may thus ascertain the relations between the given heights of the sections and the distances from the bridge to which these heights extend, and consequently the figure of the surface of the fluid through the whole extent of the eddy, which is generally prolonged to an infinite distance, but the increased or greatest height at a limited distance ceases to be evident. The formation of an eddy above bridge producing great inconveniences, both in relation to the solidity of an edifice and the difficulties to which it subjects navigation, every effort should be made to diminish it as much as possible.

It has been observed that it was dangerous to give too great an opening to the water-way, for the reason that under some arches alluvial deposits might be formed, which, acquiring by time sufficient hardness to resist the action of the current, would, in a flood, oblige the waters to flow under the arches which had remained free, and thus expose the piers to injury by attrition. For a similar reason building a bridge of two parts, separated by an island, should be avoided: it might happen that one portion becoming encumbered, the whole current would be obliged to pass under the other, and occasion its destruction: the bridges of Chazey and Roanne were carried away from this cause, and the fall of most bridges may be attributed to some error in the water-way producing too great a diminution of the section, from too little or too great a length having been given. All the elements for the calculation of the area of the water-way should be taken at the time of the greatest floods; and according to the quantity which flows at this period, the area must be determined. It is essential in rivers which will admit of them, so to dispose the arches that at low water there should be under some at least a metre in depth, in order that the navigation be not interrupted: it will always be possible to combine the different conditions between the size and the form of the arches used, and in each particular case, by making different experiments, to arrive at the best solution of the problem.

Gauthey applies the preceding ideas to the bridge over the Durance at Bonpas, which is constructed in wood between two banks, distant from each other 534 metres. The width of the river at low water is only 110 metres, and the mean depth 1·30 metres: but the flow of the river rises 3 metres, and the surface of the water-way is then 1530 square metres. The bed of the river not being confined, and the width being considerable in reference to its depth, it was difficult to ascertain the mean velocity with exactness; but at about 4 myriametres above Bonpas, near to Mirabeau, the Durance passes between two precipitous rocks, distant from each other only 180 metres. At this point, the height and velocity of the water were ascertained during the floods, more or less considerable, and the result was,

1st, That the river being 2·44 metres reduced depth, the mean velocity was 1·95 metres for a second:

2nd, That when the river was 2·92 metres reduced depth, the mean velocity was 2 44 metres per second:

3rd, That at the moment of the greatest floods, the depth of the waters being 4·87 metres, the mean velocity was 4·12 metres. Thus, in this latter case, which must be particularly considered, the expenditure of the river is 180 x 4·87 metres x 4·12 metres = 3612 cube metres per second.

The distance from Mirabeau to Bonpas not being considerable, and the river only receiving between these two points some rivulets or unimportant streams, there cannot be a

very great difference between the quantity of water which flows at either place: we may value by approximation this difference, by comparing the superficies of the basins, which supply the water at Mirabeau and Bonpas, and we find the latter surpasses the other about one-sixteenth; hence there must flow at Bonpas in a second a volume of water equal to 3838 cube metres, which for a section of 1530 square metres gives a mean rapidity of 2·51 metres. The construction of the bridge in wood diminishes a very little from the superficies of the water-way, and we may remark that the rapidity of 2·51 metres per second, which corresponds to a height of water of more than 3 metres in the bed of the river, scarcely surpasses 2·44 metres of rapidity, which the river takes naturally at Mirabeau, for a height of water of 2·92 metres. Thus the mean rapidity at Bonpas is less considerable than in other parts of the course of the river, and the waters have there an easy discharge.

The discharge of the Rhone at the bridge of St. Esprit is about 3580 square metres; that is to say, a little more than double that of the Durance at Bonpas, whilst the superficies of the basins, the waters of which flow to the Rhone at St. Esprit, is more than five times greater than that of the basins which flow into the Durance at Bonpas: thus, although the rapidity of the Rhone is very considerable under the arches of the bridge of St. Esprit, it would appear that the discharge given to the Durance is much too great. But we must observe that this river at Bonpas, being only 25 myriametres from its source, is still a torrent, whilst the Rhone at St. Esprit is no longer such.

It is then very essential in regulating the water-way of bridges to distinguish the torrents of rivers, and to have regard, in comparing the superficies of the basins, to the nature of the soil, and to the time which the waters take to flow: it may happen, as we have said above, to be necessary to construct over a river a bridge larger at a little distance from the source, than at a place farther distant, although it may have received in the interval several tributary streams.

Of the Form of Arches used in Bridges. — The arches of bridges are divided relatively to their form into three principal kinds: semicircular; those generally described by several arcs of a circle of different radii, and the form of which approaches to a demi-ellipsis; and arches which form the part of a circle, more or less. Semicircular arches are the most ancient; there is scarcely any ancient bridge in which this form is not employed, and during a long time it was generally adopted in Europe; it has the advantage of greater solidity and more facility in construction, but the inconvenience of considerably obstructing the passage of the water. Flat arches were not introduced until the end of the seventeenth century, and their adoption arose from the necessity of giving as much water-way as could be obtained without considerably increasing the height of the arch: this it effects admirably, and presents besides, when the two diameters are not very unequal, almost as much solidity and facility in the construction as the semicircular.

Of arches forming a part of a circle there are two varieties: the first is that where the springings are under water, as is the case in the first great bridge built in France, as the St. Esprit, and the ancient bridge at Avignon; but this form has the disadvantage of giving less water-way than the flattened one, and of requiring very massive tympanums. This latter defect appears to have been recognised by the first builders, for the backs of the arches are almost always simply filled with earth, or discharged by means of a number of small arches. In the second case the springing of the arches are raised on piers nearly the height of the greatest rise of the river, as at the Pont Louis XVI. at Paris, which generally requires the arch to be much flattened; hence it results that the lateral pressure of the voussoirs is very considerable, and great care is required in the construction, in order that the arch should not sink after the striking of the centre, which has sometimes occurred. The manner in which the thrust of arches of this kind exerts itself is different from that in which it acts in others; they do not generally tend to overthrow their abutments, but to make them slide horizontally; we shall indicate hereafter the means for resisting this thrust without incurring any considerable expense. We shall also find that the resistance opposed by the springing of the arches to the current when they are plunged in it, is one of the principal causes of the wearing away that takes place at the foot of the piers: bridges with circular arches have in this particular a great advantage over others, when their springing is not reached by the waters of the river.

It is not possible to give general rules for the selection of these different kinds of arches; the decision must be made in each particular case according to local circumstances, as the width of the water-way, the height with regard to either high or low water, the height at which the surface of the pavement of the bridge may be placed, the obligation which sometimes occurs of destroying one arch, and consequently making the piers perform the functions of abutments, are the principal considerations: due regard must also be paid to the nature of the materials and the degree of resistance they may offer.

To the three species of arches mentioned, which are those now in use, we may add the forms employed by the Arabs, and above all the Gothic, composed of two arcs of a circle, and known under the name of O G: this latter has the inconvenience of considerably diminishing the water-way; but this defect is easily remedied by making openings in the

tympanums, as in one of the bridges of Pavia, and there may be cases in which they may be used with advantage: taste should proscribe none, for each has its merit when properly applied.

On the Width of Arches of Bridges. — Although the width of the arches depends generally on the particular circumstances of the place where the bridge is to be built, a few observations may assist us relative to this point. Small arches principally suit tranquil rivers, whose waters do not rise to a great height, whence it is generally easy to lay the foundations, and no fears need arise with regard to multiplying the points of support: great arches on the contrary are adapted for torrents, in which it is generally difficult to obtain foundations, and which, carrying down rocks and trees, damage the piers and springing of the arches, which in such cases consequently should be placed above the surface of the waters. In great rivers large arches are preferable, above all where strong eddies frequently occur; but the cost which the foundation of the piers would entail must greatly influence the decision on this subject: due consideration must also be given to the nature of the materials employed, which require to be of greater solidity for large than for small bridges, also to the size of the craft navigating the river, for which a commodious passage must be left. With regard to the relative openings of the arches, these two plans may be adopted, either to make them equal to each other, or to diminish them progressively from the centre to the abutments. If all the arches be equal, a level line may be preserved and the same centres used; but then the height of the approaches must be augmented, and consequently it is necessary to enlarge the embankments, thereby raising them above the houses in the vicinity: another inconvenience arises from the want of fall to drain off the rain water, which, if allowed to remain long on the bridge, penetrates by degrees down to the covering of the extrados, and injures it: much inclination cannot be given to the channels which convey the water to the gullies by which it is ejected into the river, whether the waters flow off at the extremities of the bridge, or by the openings practised through the arches themselves. If the diameters of the arches are unequal, these latter inconveniences disappear; each side of the pavement of the bridge may then have a fall, which, however, must not exceed 3 in 100: the difficulties occasioned by lofty embankments are at the same time overcome. It is possible, however, to unite the advantages of these two methods, by giving to all the arches the same opening, but placing the springing at levels decreasing from the middle to the extremities of the bridge: it is necessary to leave the arches of a sufficient height that in floods, trees, &c., which the river carries down, may pass freely under them.

Of the Breadth of Bridges. — The breadth which should be given to bridges depends solely on their situation, and must be regulated by the importance of the road on which they have been constructed, or the population of the town to which they belong; and it is essential not to make the breadth too considerable, because it uselessly increases the expense. If the bridge be constructed in the country for a road in its vicinity, it will be sufficient to give it a width of from 12 to 15 feet, if not very long; for a road of the second class, the width should be from 18 to 22 feet, which will be sufficient for the passage at one time of two carriages and foot passengers: for a road of the first class it should be from 25 to 35 feet in width. In the interior of cities the width may vary from 30 to 60 feet, with relation to the population and commercial activity, but it should seldom exceed this latter limit, though the Pont Neuf at Paris, which is without doubt one of the most frequented bridges in existence, is 72 feet in width between the parapets.

Arches used in the Construction of Bridges, when semicircular, should have their centre at the level of the top of the foundations, or that of low water; circumstances sometimes require it to be elevated above when it is raised on piers.

Flat Arches with three Centres, or two. — The form of these arches is not entirely determined either by the span or the height; it is possible to describe on two given diameters an infinity of different curves; the sole condition to which the curve of flat arches is subject is, that the tangent at the summit be horizontal, and those at the springing be vertical. As a semi-ellipsis satisfies these two conditions, it appears natural to select this curve, which, decreasing regularly from the springing to the summit, is peculiarly agreeable to the eye: but it has the inconvenience of requiring a different template for each voussoir composing the arch; neither does it allow so much water-way as the curves of which we are about to treat, unless the difference in the two diameters of the arch be made very considerable.

Instead of the semi-ellipsis, curves are generally employed, formed by arcs of a circle, since they enable the engineer to determine with ease the length and the radii of these arcs, and thus to give the most convenient form to the arch: two conditions must, however, be fulfilled: —

1st, That the outline of the first arc of the curve, setting out from the springing, should contain that of an ellipsis, constructed on the two diameters of the flat arch, in order to obtain for the latter greater water-way than it would have if the ellipsis were employed.

2nd, That the radius of the arc at the summit should not surpass a certain limit; for the

value of this no general rule can be given, but it must scarcely exceed the width of the arch; and if particular circumstances require a greater radius, the joints of the voussoirs must not be directed to the centre of the arch, but towards a nearer point.

These two first conditions fulfilled, the number of arcs of a circle of which the arch shall be composed must be determined; it must not be less than 3, nor exceed 11. The following rules for describing these arches are usually adopted by engineers.

Flat Arches described with three Arcs of a Circle.— The length of the radii of the three arcs composing the flat arch not being determined, when the two diameters of the curve are fixed, another element must be introduced. We will suppose first that the three arcs are all of 60°; that is to say, each equal to the sixth part of the circumference.

The half of the span of the arch A C is equal to a, and its height C D = b; the centres of the two arches described at the springing will necessarily be situated in the two points F, G, in the line A B, and the centre of the third arch in a point E in the line D C prolonged; one of these centres being found, the two others will be also.

Call x the distance from the point C, in the middle of A B, to the centre G. The triangle F G E being equilateral, we have E G equal F G, and, consequently,

$$C E + C D = F G + G B;$$

or $$\sqrt{3} \cdot x + b = x + a;$$

and by resolving this equation,

$$x = \frac{a-b}{\sqrt{3}-1} = \frac{\sqrt{3}+1}{2}(a-b).$$

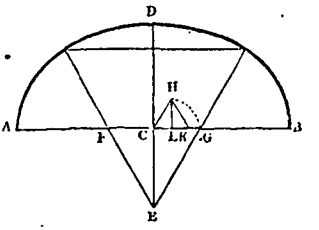


Fig. 2703.

This value is constructed by setting off from the point C the line C K = $a-b$, and after having formed on it the equilateral triangle C H K, carrying from L to G the height L H of the triangle. The position of the centres of the three arches may also be obtained by tracing the quarter of the circle A I H (fig. 2704.) and the equilateral triangle A C I; then drawing D M parallel to H I, and M F E parallel to I C.

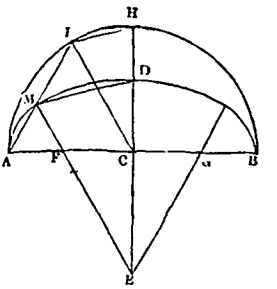


Fig. 2704.

Let us now suppose that one of our conditions is that the greater and lesser arc differ from each other as little as possible. Call the half of the span of the arch A C = a, and its height C D = b; the radius A F of the arc of the springing y, and x that of the arc of the summit, the centre of which is in E; we shall have by reason of the rectangular triangle C F E,

$$(x-y)^2 = (x-b)^2 + (a-y)^2.$$

In resolving this equation with relation to x, we find

$$x = \frac{\frac{1}{2}(b^2+a^2) - ay}{b-y}$$

We shall then have for the expression of the relation of the two radii,

$$\frac{x}{y} = \frac{\frac{1}{2}(b^2+a^2) - y}{by - y^2}.$$

By making its differential equal zero, and finding the value of y, we find, after abridging, $b^2 + a^2 = c^2$,

$$y = \frac{bc}{c + (a-b)},$$

putting this value in that of x, we deduce from it,

$$x = \frac{ac}{c-(a-b)}.$$

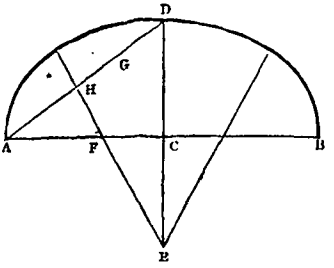


Fig. 2705.

These two expressions are formed by cutting off from the line A D (fig. 2705.) the distance D G, equal to $a-b$, and raising on the middle of the remaining part A G the perpendicular H E; the points E, F, where it meets the two diameters of the curve, will be the centres sought. This method gives a greater difference between the lengths of the two arcs than the preceding, which appears preferable. When the relation of the two diameters is not less than one-third, the difference of the radii of the arcs of which the flat arch is composed is not sufficient for the passage from one to the other to be marked, and produces a disagreeable effect, and it must be described with three arcs of a circle; but when the arch is flatter, a greater number must be employed.

The forms which are here described for the arches of bridges are given without any reference to their equilibrium, a subject which has been found one of the most difficult the mathematician has had to consider, and perhaps of little value to the practical engineer, if it could be rightly solved; for the latter must ever be guided by those rules which experience dictates; if he follow implicitly in the path theory points out, he may fail, from observing the nice and too often close deductions made in her calculations: when, however, theory is borne out by practice, we are warranted in submitting to all that is propounded. Emerson's Fluxions and Hutton's Principles of Bridges may be consulted by the reader who is desirous of becoming acquainted with these delicate but important applications of mathematical science. The practical method of hanging up a semicircular polygon, with weights at the joints of each link or side, will afford the student data for calculating the form that should be given to the extradossing of an arch of any figure, as the weights which would pull it into any given curve would, if placed upon an arch, maintain it in the same position, or cause it to be in a state of equilibrium.

Of flat Arches described with more than three Arcs of a Circle. — Different methods have been employed to determine the positions of the centre, and the length of the radii of the arcs of which these curves should be composed; the following was that adopted for the arches of the bridge at Neuilly.

After having fixed the radius F B of the first arc at the springing, on the prolongation of the lesser diameter C D, a distance is taken, C E, which is arbitrarily made triple C F, and which might bear any other proportion to that line: having then divided C E into five equal parts, C F into five parts, which are to each other in the proportion of the numbers 1, 2, 3, 4, and 5, join the points of division by the lines L F, M G, N H, O I, E K; take for centres of the different arcs which compose the arch the points E, P, Q, R, S, F, which are found at the respective intersection of these lines.

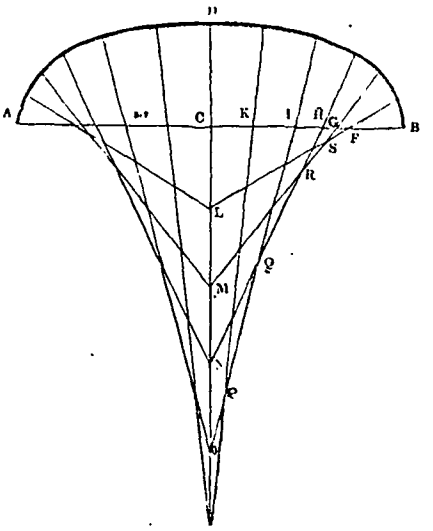


Fig. 2706.

In the curve described in this manner, the relation of the height C D to the span A B depends on the data from which we started, that is to say, on the length C F, and of its proportion to C E. But when a flat arch is to be described, the two diameters are generally fixed beforehand, so that after having constructed a curve by the preceding method, that curve must be so modified that the height C D becomes precisely equal to that which is assumed. Call a half the span of the arch required, and b its height, x the dimension C F, and y that of C E. Suppose, moreover, that the primitive and arbitrary values which shall have been given to C F and C E be represented by n and m; and that by the development of the portion of the polygon E P Q R S F B, a length $= s$ results, whilst that in the flat arch described on the diameters a and b this length will be $= z$. We have the relation,

$$z + a - x = y + b;$$

and if we suppose the figure that will be constructed on the lines x and y to be similar to the figure E C F, constructed on the lines C F $= n$, and C E $= m$, we shall have

$$y = \frac{mx}{n}, z = \frac{sx}{n};$$

substituting these values in the preceding equation and taking that of x, we find

$$x = \frac{n(a-b)}{m+n-s};$$

which is the value to be given to C F, in order that the opening and the height of the arch may be precisely equal to the lines represented by a and b.

This method is applied to the flat arch, composed of any number of arcs whatever: by means of the same centres, parallel curves may be described, in which the proportions of the diameters shall vary; and if the ratio between C F and C E be correctly determined, curves will be obtained, which, although having the same axis, will assume different forms,

and afford more or less passage for the water. The tediousness of the preceding method is its only objection; but in the case in which the arch would be lowered $\frac{1}{4}$, it is useless to compose the flat arch of so large a number of arcs of a circle; five will generally be found a sufficient number, and the process be much simplified.

Suppose, for example, (fig. 2706.) that the length A F and D E of the radii of the arc at the springing and the summit be determined, and represented by r R: call ρ the radius of the intermediate arc, which may be determined by the condition of its being a mean proportional between r and R: then we shall have

$$\rho = \sqrt{\mathrm{R}r}.$$

From the point F as a centre, and with a radius equal to $\rho - r$, describe an arc; and from the point E, with a radius equal to $\mathrm{R} - \rho$, a second, which shall cut the first in G; the point G will be the centre of an arc uniting that at the springing and that of the summit.

If a flat arch described from seven centres is required, we must determine two mean proportionals, ρ and ρ', between the radii of the extreme arcs r and R, which would give

$$\rho = \sqrt[3]{\mathrm{R}r^2}, \text{ and } \rho' = \sqrt[3]{\mathrm{R}^2 r}:$$

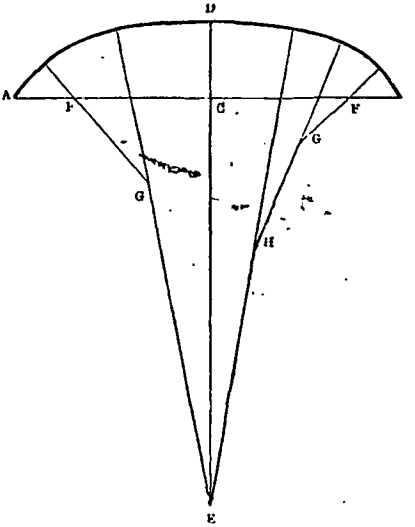


Fig. 2707.

from the point F as a centre, (fig. 2707.), and with the radius equal to $\rho - r$, describe an arc which should contain the centre of the arcs, the radius of which is ρ; and from the point E, and with the radius $\mathrm{E\,H} = \mathrm{R} - \rho'$, a second arc, which should contain the centre of the arc of which ρ' is the radius. To fix on each of these arcs the respective position of the two centres, draw a line H G, the length of which must be equal to $\rho' - \rho$, between the two arcs; but as the position of this line is not determined by this single condition, we must imagine it to be so fixed, that the length of the arcs of which the arch is composed decreases uniformly from the summit to the springing. This method may be extended to flat arches composed of a greater number of arcs, but it is useless to use more than five.

In constructing moulds for the arches of bridges, it is not possible, except for the part near the springing, to use beam compasses for tracing the arcs of which they are composed; the engineer commences, therefore, by fixing the extremities of each of these arcs, of which the data have been calculated beforehand; and they are described by means of two rules firmly united, so as to form an angle the supplement of which is equal to half of the arc. This angle is made to move so that the sides always pass through the extreme points of the arc: the summit gives the intermediate points.

Flat Arches not formed by Arcs of a Circle. — The difficulty of exactly tracing the projected curve, when composed of several arcs of a circle, has given rise to different methods for describing the flat arch.

Carpenters generally use, for the purpose of uniting two sides of an angle A E D a curve, the form of which may be obtained by dividing the two sides of the angle into the same number of equal parts, and by joining the points of division by lines regarded as tangents to the curve, and which, supposing them infinitely near, determine each of these points by their successive intersections; in performing this operation for an angle, a portion of the curve equal to the first will be obtained, which will complete the description of the arch A D C.

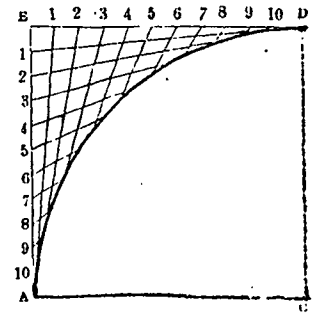


Fig. 2708.

It has long been remarked, that the curve traced by the preceding method was a portion of a parabola, the summit of which is situated between the points A and D; it gives more water-way than a flat arch composed of three arcs of a circle, or a semicircle which could be constructed on the same

axis; it has this advantage over the preceding form, and is more easily described, but it is attended with an inconvenience common to most of these curves, viz. its disagreeable appearance to the eye: in the parabola the value of the radius of the curve is a minimum to the summit of the curve, and from the position of the summit, the curve does not diminish progressively from the springing to the highest point of the arch.

It has also been proposed to form flat arches with two arcs of a circle, setting off from the springing and united at the summit of the vault by a portion of the catenary. Curves of this kind have a greater water-way than the ordinary segmental arches, and are certainly to be preferred on this account. The ellipsis whose curvature diminishes progressively from the springing to the summit is decidedly the most elegant figure that can be adopted for the intrados of flat arches: it may be readily drawn by the following simple method, which is recommended by M. de Prony.

Given half the great arch C A, and the lesser semi-axis C B of the ellipsis, describe from the point C, with C A for a radius, a circle; then move a square so that one of its sides n F, passing continually through the focus F, the summit n of the right angle shall always follow this circle; the other side nt of the square will be a tangent to the ellipsis: by tracing thus a number of tangents, the curve may be obtained with the greatest accuracy, and we shall have at the same time the direction of the tangents and the normals.

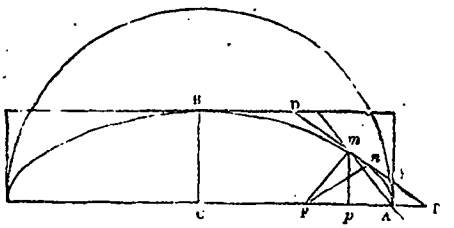


Fig 2709.

The same method may be applied to the hyperbola: for the parabola, the circle becomes a right line tangent to the summit of the curve. This process possesses the advantage of not requiring an area greater than the rectangle circumscribing the curve. M. de Prony has also given a very simple formula for determining the direction of the tangent tT, when the point t is given, as well as the position of the point m, by means of its co-ordinates Ap, mp.

Calling A the major semi-axis A C;

B the minor semi-axis B C;

x and y the co-ordinates Ap, mp;

a the distance At;

b the distance AT;

k the distance Dt;

and for conciseness making,

$$\frac{B}{a} = \chi, \text{ we have}$$

$$y = \frac{A}{B}\sqrt{2Ax - x^2}.$$

$$a = \frac{Bx}{\sqrt{2Ax - x}}.$$

$$x = \frac{2A}{\chi^2 + 1}, \quad y = \frac{2B\chi}{\chi^2 + 1}.$$

$$b = \frac{2A}{\chi^2 - 1}, \quad k = \frac{2A}{+1}.$$

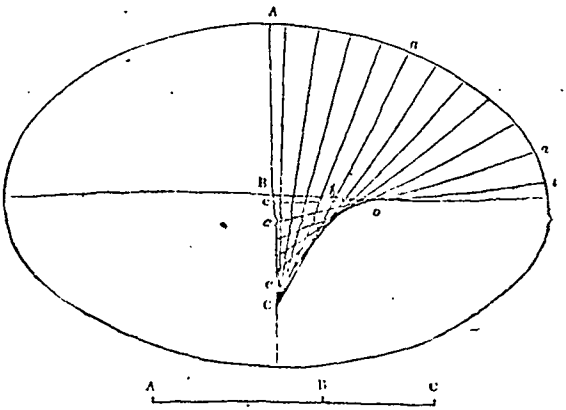


Fig. 2710.

These formulæ, the calculation of which is very easy, may be used with advantage. When the curve of great arches is formed by the arc of a circle, the direction of the tangents, and the position of a great number of points, should be fixed by a method analogous to the preceding.

A very simple process, and not requiring any instrument, may be found useful to the engineer: having the major and minor semi-axis, set off their respective lengths from the same point on a slip of card, (or a rod, if a large ellipsis be required); then commencing from one extremity of the minor semi-axis, as A, turn the slip of card in the direction of a to A, observing always to keep the point B continually touching the major semi-axis, and C the minor; the card or rod will then assume the positions marked a, b, c, and by keeping a pencil at a, the curve is drawn at once: a, b, c, will be the joints of an elliptical arch.

The Bridge of Saumur, on the Loire, of which we have given some account at page 258., was executed by De Cessart, who published a series of tables on Chezy's principles for setting out arches, approaching the elliptical form, from 24 feet to 100 feet span: the diagram was drawn for an arch of 60 feet opening, and by reference to the table the distance from one letter to the other will be found; the radiating lines from F, N, O, G,

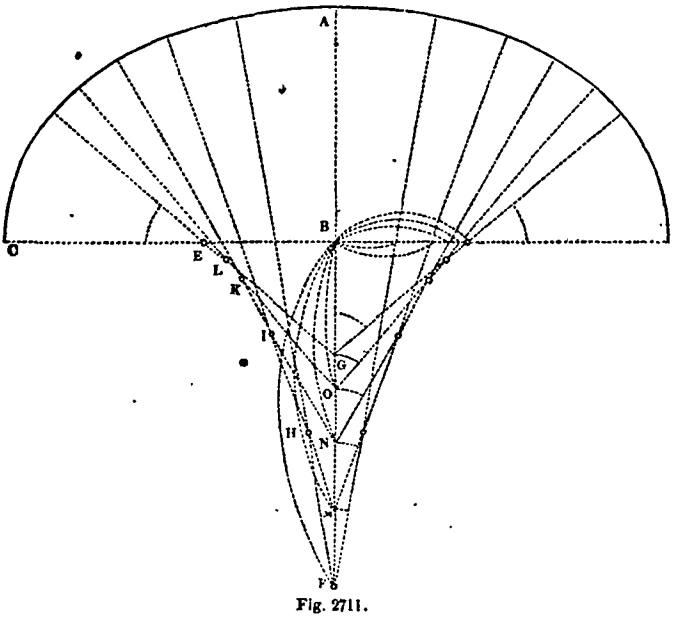


Fig. 2711.

&c., being set off upon arcs of from 10, 20, 30, 40, 50 degrees. There are several calculations which accompany these tables which it is unnecessary to dilate upon: the dimensions are all in French feet and inches, which are here retained. For a considerable time this system of setting out arches was adopted in France, and the bridges so constructed have been very much admired.

24 Feet Opening.

A F = 20 feet 9 inches 11 lines 11⅜ points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	8	4	10	9½	E C =	7	2	4	9⅜
B G =	4	0	8	7½	E L =	1	1	0	9⅜
G O =	1	4	9	7½	L K =	0	9	7	6½
O N =	1	10	4	9⅜	K I =	2	8	7	9⅜
N M =	2	4	0	0	I H =	3	11	0	0
M F =	2	9	7	2⅜	H F =	5	6	2	0
A F =	20	9	11	11⅜	Idem.	20	9	11	11⅜

30 Feet Opening.

A F = 26 feet 0 inches 5 lines 9 points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	10	6	1	3	E C =	0	0	0	0
B G =	5	0	4	6	E L =	1	4	4	0
C O =	1	9	0	0	L K =	1	0	0	3
O N =	2	4	0	0	K I =	2	10	8	0
N M =	2	11	0	0	I H =	4	10	9	0
M F =	3	6	0	0	H F =	6	10	8	6
A F =	26	0	5	9	Idem	26	0	5	9

36 Feet Opening.

A F = 31 feet 2 inches 11 lines 8⅜ points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	12	7	3	10½	E C =	10	9	7	2⅝
B G =	6	0	5	4½	E L =	1	7	7	2⅝
G O =	2	1	2	4½	L K =	1	2	5	1½
O N =	2	9	7	2⅝	K I =	3	5	7	2⅝
N M =	3	6	0	0	I H =	5	10	6	0
M F =	4	2	4	9⅜	H F =	8	3	3	0
A F =	31	2	11	8⅜	Idem.	31	2	11	8⅜

42 Feet Opening.

A F = 36 feet 5 inches 5 lines 7 points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	14	8	6	6⅜	E C =	12	7	2	4⅓
B G =	7	0	6	3⅜	E L =	1	10	10	4
G O =	2	5	4	9	L K =	1	4	9	11⅔
O N =	3	3	2	4⅓	K I =	4	0	6	4⅓
N M =	4	1	0	0	I H =	6	10	3	0
M F =	4	10	9	7⅓	H F =	9	7	9	6
A F =	36	5	5	7	Idem.	36	5	5	7

48 *Feet Opening.*

A F = 41 feet 7 inches 11 lines 6⅔ points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	16	9	9	2	E C =	14	4	9	7
B G =	8	0	7	2⅔	E L =	2	2	1	7⅔
G O =	2	9	7	2	L K =	1	7	2	9
O N =	3	8	9	8	K I =	4	7	5	7
N M =	4	11	10	0	I H =	7	10	0	0
M F =	5	3	4	4	H F =	11	0	4	0
A F =	41	7	11	6⅔	Idem.	41	7	11	6⅔

54 *Feet Opening.*

A F = 46 feet 10 inches 5 lines 5⅓ points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	18	10	11	10	E C =	16	2	4	9⅓
B G =	9	0	7	0⅓	E L =	2	5	4	9⅓
G O =	3	1	8	0⅓	L K =	1	9	7	7
O N =	4	2	8	4⅓	K I =	5	2	4	9
N M =	5	3	0	0	I H =	8	9	9	0
M F =	6	3	6	2⅔	H F =	12	4	10	6
A F =	46	10	5	5⅓	Idem.	46	10	5	5⅓

60 *Feet Opening.*

A F = 52 feet 0 inches 11 lines 6 points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	21	0	2	6	E C =	18	0	0	0
B G =	10	0	9	0	E L =	2	8	8	0
G O =	3	6	0	0	L K =	2	0	0	6
O N =	4	8	0	0	K I =	5	9	4	0
N M =	5	10	0	0	I H =	9	9	6	0
M F =	7	0	0	0	H F =	13	9	5	0
A F =	52	0	11	6	Idem.	52	0	11	6

66 *Feet Opening.*

A F = 57 feet 3 inches 5 lines 2⅔ points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	23	1	5	1⅓	E C =	19	9	7	2⅔
B G =	11	0	9	10	E L =	2	11	11	1⅓
G O =	3	10	2	4⅔	L K =	2	2	5	4
O N =	5	1	7	2	K I =	6	4	3	2
N M =	6	5	0	0	I H =	10	9	3	0
M F =	7	8	4	9	H F =	15	1	11	5
A F =	57	3	5	2⅔	Idem.	57	3	5	2⅔

72 *Feet Opening.*

A F = 62 feet 5 inches 11 lines 2⅓ points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A F =	25	2	7	9	E C =	21	7	2	4⅓
B G =	12	0	10	9	E L =	3	3	2	2
G O =	4	2	4	9	L K =	2	4	10	2
O N =	5	7	2	4⅓	K I =	6	11	2	2
N M =	7	0	0	0	I H =	11	9	0	0
M F =	8	4	9	7	H F =	16	6	6	4
A F =	62	5	11	2⅓	Idem.	62	5	11	2⅓

90 *Feet Opening.*

A F = 78 feet 1 inch 5 lines 3 points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	31	6	3	9	E C =	27	0	0	0
B G =	15	1	1	6	E L =	4	1	0	0
G O =	5	3	0	0	L K =	3	0	0	7
O N =	7	0	0	0	K I =	8	8	0	0
N M =	8	9	0	0	I H =	14	8	5	0
M F =	10	6	0	0	H F =	20	8	1	8
A F =	78	1	5	3	Idem.	78	1	5	3

95 *Feet Opening.*

A F = 82 feet 5 inches 6 lines 2⅔ points.

	ft.	in.	l.	p.		ft.	in	l.	p.
A B =	33	3	3	11⅔	E C =	28	6	0	0
B G =	15	11	2	3	E L =	4	3	8	8
G O =	5	6	6	0	L K =	3	2	0	9⅓
O N =	7	4	8	0	K I =	9	1	9	4
N M =	9	2	10	0	I H =	15	6	0	6
M F =	11	1	0	0	H F =	21	9	10	11
A F =	82	5	6	2⅔	Idem.	82	5	6	2⅔

100 *Feet Opening.*

A F = 86 feet 9 inches 7 lines 2 points.

	ft.	in.	l.	p.		ft.	in.	l.	p.
A B =	35	0	4	2	E C =	30	0	0	0
B G =	16	9	3	0	E L =	4	6	5	4
G O =	5	10	0	0	L K =	3	4	0	10
O N =	7	9	4	0	K I =	9	7	6	8
N M =	9	8	8	0	I H =	16	3	10	0
M F =	11	8	0	0	H F =	22	11	8	4
A F =	86	9	7	2	Idem.	86	9	7	2

Rondelet gives in his "L'Art de Batir," the following methods for drawing arches formed of several circular arcs. For that represented in fig. 2709., after having determined the semi-diameter A C at 60 feet, and the length of the radius A *d* of the arcs at the springing at one-third of A C, divide *d* C into fifteen equal parts; give one to *di*, two to *ik*, three to *kl*, four to *lm*, and five to *m* C: having then fixed C H at twice A C, divide it into five equal parts, and from the points of division D, E, F, G, H, draw lines through the divisions on the horizontal line *d* C, and prolong them sufficiently to determine the form of the arc which results from their intersection, as D *d* I, E *i* K, F *k* L, G *l* M, and H *m* N, whose points of intersection, *e*, *f*, *g*, *h*, give the centres of the intermediate arcs; thus *d* is the centre of the arc A I, *e* that of the arc I K, *f* that of the arc K L, *g* that of the arc L M, *h* that of M N, and H that of N B. The intersections marked *x*, *x*, *v*, indicate the curvature of a regular ellipsis, and is here introduced in order to show the difference of the two curves.

Fig. 2710. is an arch composed of six arcs of a circle, which increase in arithmetical progression from the centre of the key to the springing. After having drawn the diagonal P C, and described the quarter circle A Q, the angle A P *n* is made equal to the angle *o* P Q, and the prolongation of the line P *n* gives the point *d* on the semi-diameter A C, and the

point H on the axis B C prolonged; the two points D, H are the centres of two extreme ares: to have those of the four intermediate arcs, draw I D parallel to P C, which gives the first arc A I of 27 degrees: by calculation we find I K will be 22 degrees 12 minutes, K L 17 degrees 24 minutes, L M 12 degrees 36 minutes, M N 7 degrees 48 minutes, and N B 3 degrees, making up 90 degrees for the whole. From C as a centre, and with C A as a radius, describe the quarter circle A R; make V R equal to one-fifth, or 18 degrees: this arc, divided into six, gives tR 3 degrees, forming the first term of the arithmetical progression: to have the difference, the arc A V is divided into fifteen, which gives sV for this value; D H being then divided into ten parts, four are given to D E, three to E F, two to F G, and one to G H. From the point H with radius equal to C R, having described an arc, tR is set off from 1 to 2; draw H 2 N, which forms an angle of 3 degrees with H B. From the point G, with C R for a radius, describe a second arc, on which set off from 3 to 4 the measure of the two ares B N and N M taken together, equal to twice tr and sV, and draw G 4 M, which forms with H B an angle of 10 degrees 48 minutes, and with G N one of 7 degrees 48 minutes.

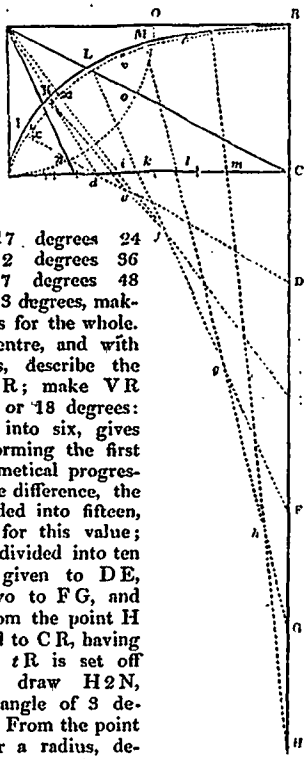


Fig. 2712.

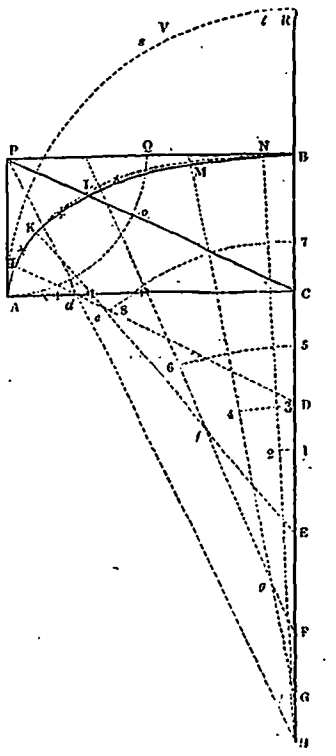


Fig. 2713.

From the point F, with the same radius, a third arc is described, on which measure off the three arcs B N, N M, and M L, which is equal to three times tR and three times sV, from 5 to 6, and draw F 6 L, forming with H B an angle of 23 degrees 24 minutes, and with M G an angle of 12 degrees 36 minutes.

From the point E a fourth arc is described, as are other arcs, from F and G: the points h, g, f, e, where the lines intersect, are the centres of the four intermediate ares.

Fig. 2711. is formed of eleven equal arcs, to draw which the centres d, H, are determined as in the preceding figures: after drawing the diagonal P C, the angle A P d is made equal to o P Q, and P d is prolonged to H: from the point C, with the radius A C, draw the quarter circle A R, and divide it into six equal parts: from the point d raise a perpendicular to the intersection q, on the radius C 1, drawn from the first division of the quarter circle: from the point q draw qr parallel to A C, which cut the radii drawn from the divisions 2, 3, 4, 5, in the points 6, 7, 8, 9. After setting out the parts q6, 67, 78, 89, and 9r, from C to m, m to l, l to k, k to i, and i to d, from these points d, i, k, l, m, with a radius equal to C A, draw the ares of circles, on which set off the arc A 1 of 15 degrees, once from 10 to D, twice from 11 to E, thrice from 12 to F, four times from 13 to G, and five times from 14 to 15, through the points D d, E i, F k, G l, H m, draw the lines whose prolongation makes the ares A I, I K, K L, L M, M N, and N B, of the same number of degrees; the intersection of these lines gives the centres d, e, f, g, h, and H, to describe the several arcs.

Fig. 2712. An arch of the same diameter and height as the preceding may have the quarter circle A R divided into six equal parts at 1, 2, 3, 4, 5, through which lines are drawn parallel to R C: from the point C, with C B as a radius, another quarter circle is described, also divided into six equal parts, in the points 6, 7, 8, 9, 0, through which lines

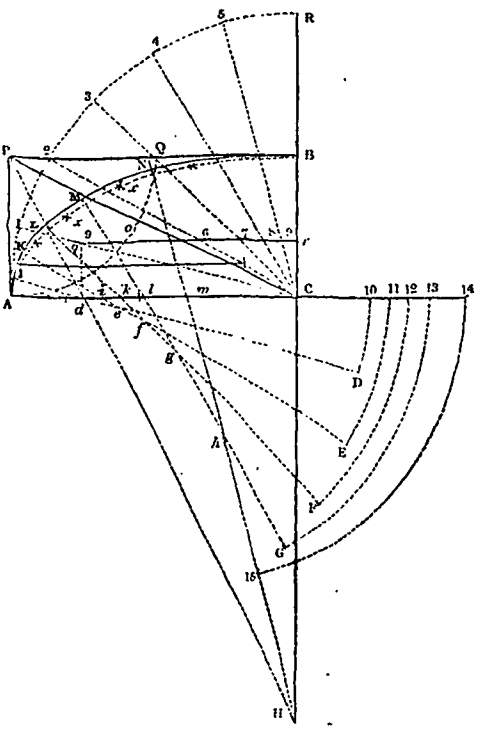


Fig. 2714.

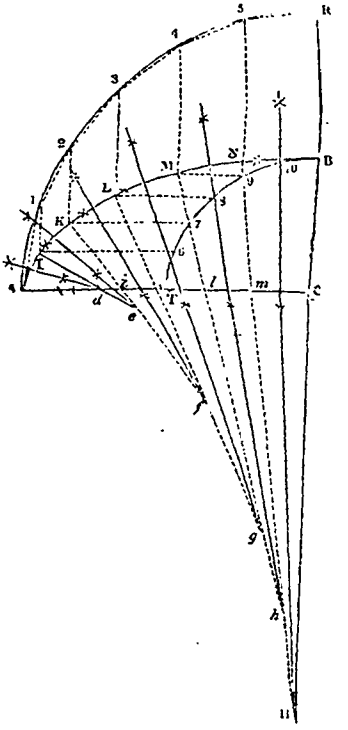


Fig. 2715.

are drawn parallel to A C, intersecting the first in the points I, K, L, M, N, through which other lines are drawn forming a polygon: on the middle of each of the sides of this polygon perpendiculars are raised, some of which intersect the semi-diameters A C and B C in the points *d*, H, and the others intersect one another at *e*, *f*, *g*, *h*, which are the centres of the arcs answering to each side of the polygon; this curve approaches the nearest to the ellipsis.

The arches of the bridge at Neuilly were composed of eleven portions of the arcs of circles, each of which had their respective centres, as shown in fig. 2709.; and in fig. 2720. we have Perronet's manner of tracing the curve for the formation of the centres; the small figures at the sides exhibit portions of the operation of constructing the curve. Fig. 2721. shows how the piers were placed, and 2716, 2717, 2718, 2719, the manner in which the joints of the pendentives were set out. Fig. 2713. exhibits one of the arches after the centre was removed; and fig. 2731. the joints of half one of the arches.

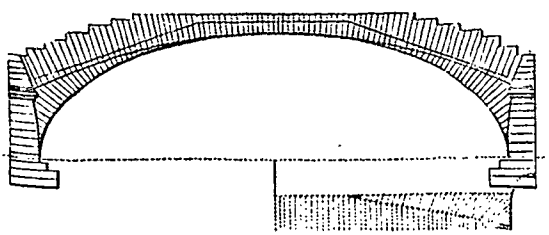


Fig. 2716. BRIDGE OF NEUILLY.

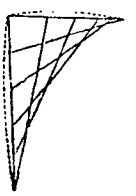


Fig. 2717

It is unnecessary to enter into the minute calculations made by Perronet, which are contained in his "*Description de la Courbure et des Epures des Arches du Pont de*

Neuilly :" it is sufficient to observe, that the engineers of that period attempted to obtain the elegance of an elliptic arch by an assimilation of several curves, taken from as many

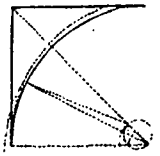


Fig. 2718.

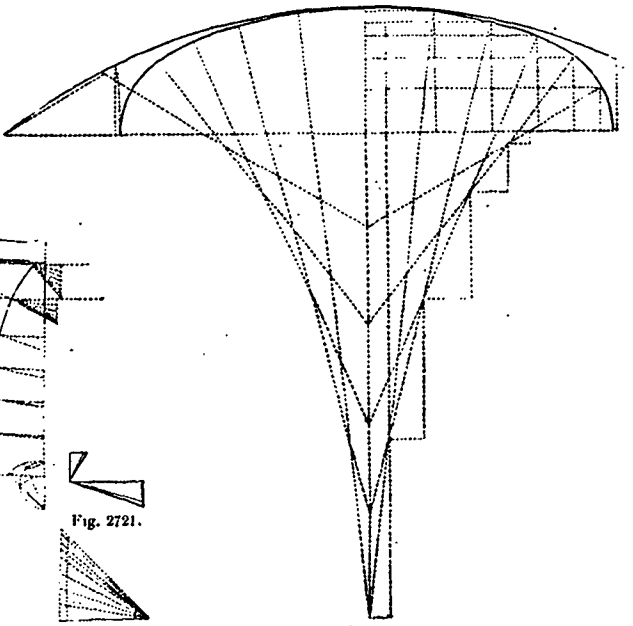


Fig. 2723.

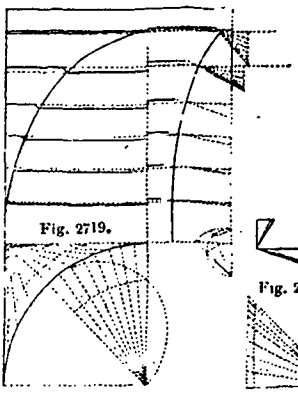


Fig. 2719.

Fig. 2720.

Fig. 2721.

Fig. 2722.

circles: by a reference to their calculations, it will be seen how nearly they accomplished the object they had in view.

The ellipsis was supposed to have no portions of its curvature alike, but that it varied throughout. Perronet, in the bridge at Mantes, employed the method which had been previously adopted by M. Hupeau, to render portions of a number of circles alike in form with the ellipsis. In fig. 2724. we have his manner of tracing the arch with three centres; in fig. 2725. it is composed of five arcs of a circle, with the portion of an oval above; in fig. 2731. is represented the simple method of describing an arch with three centres; fig. 2732. shows one of the small arches of the bridge at Mantes, with its upper and lower starlings; fig. 2726. and 2727. the mouldings of the parapets; fig. 2731. the sort of wooden compasses made to strike the several arcs; fig. 2729. the courses as laid in the arch, as does fig. 2730. on a different level.

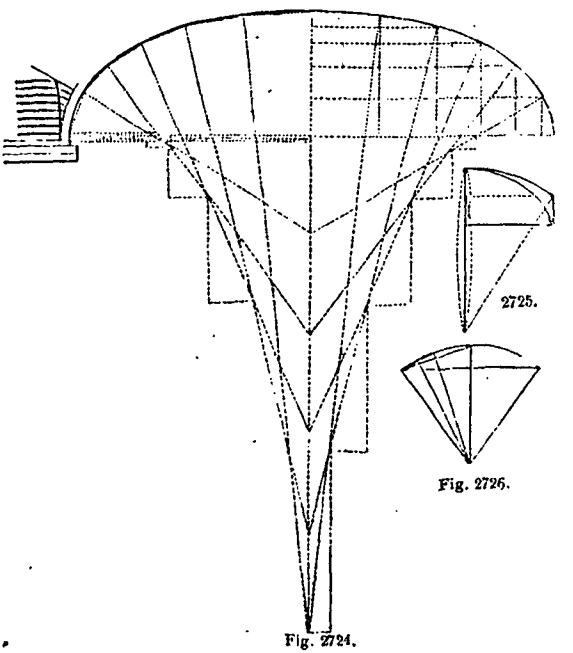


Fig. 2724.

2725.

Fig. 2726.

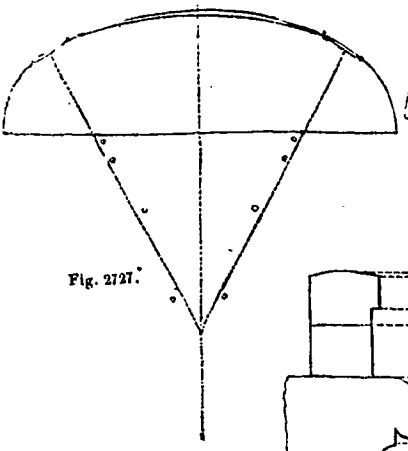


Fig. 2727.

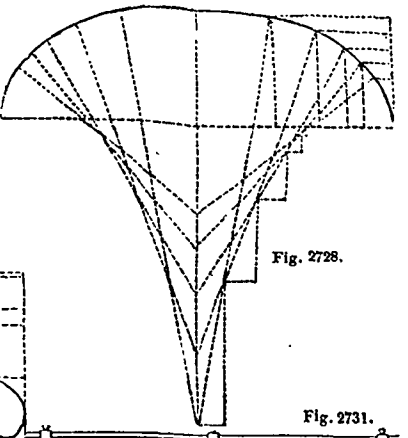


Fig. 2728.

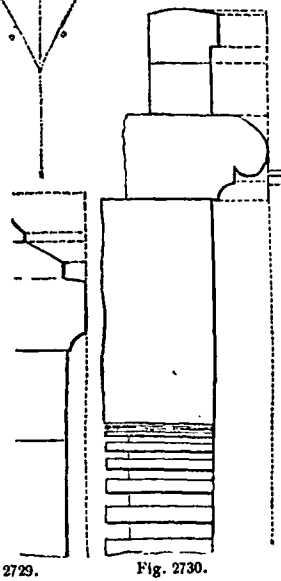


Fig. 2729.

Fig. 2730.

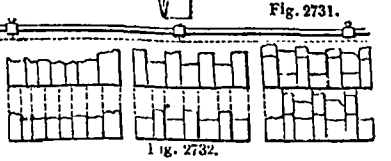


Fig. 2731.

Fig. 2732.

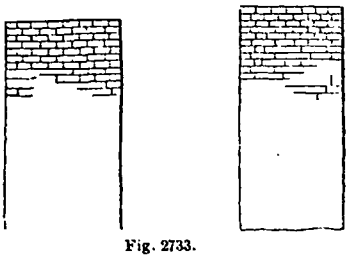


Fig. 2733.

Thickness to be given to the Key-stones of the Arch. — Having determined the form of the curve, the thickness of the key must next be considered, as upon it depends the dimensions of the abutments. Alberti, Palladio, and Serlio, have allowed the twelfth, the fifteenth, and seventeenth parts of the span of the arch, without regarding the nature or quality of the stone employed. Perronet asserts that the twenty-fourth of the opening of the arch should be the depth of the key-stone, and Gauthey thinks thirteen inches a proper dimension for all arches which have a less span than 6 feet 6 inches: for those above that, up to 52 feet, he makes the key-stone the twenty-eighth part of their

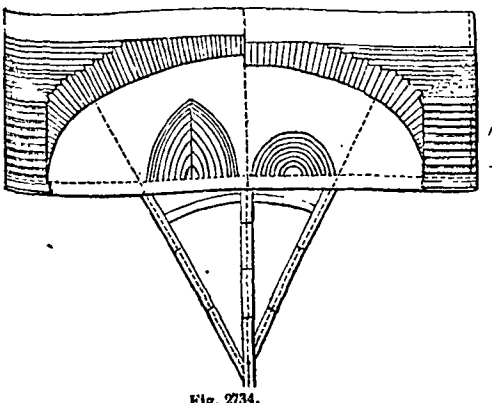


Fig. 2734.

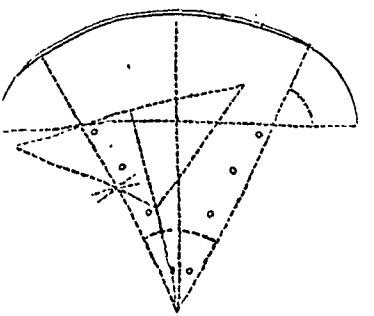


Fig. 2735.

span, in addition to the 18 inches, and for arches exceeding these the twenty-fourth part for the first 104 feet, and the forty-eighth for the remainder.

In the segmental arch of Wide Bargate Bridge, at Boston, in Lincolnshire, whose span is 50 feet, the height of the key-stone is 2 feet; at Conan Bridge, in Ross-shire, whose span is 65 feet, the key is 2 feet 6 inches; at Kelso Bridge, the span of which is 72 feet, it is 3 feet 3 inches; Darlinton on the Trent, which has a span of 80 feet, the key-stone is 3 feet; Hobhole, near Boston, whose arch is 90 feet span, the key is 3 feet 9 inches; Wellington Bridge, over the Aire, where the span is 100 feet, the depth of the key is 4 feet. The arches of Waterloo Bridge, London, are 120 feet span, and the key-stone is 4 feet 6 inches. At Vieille Brioude Bridge, erected in 1454, over the Allier, where the span was 183 feet 3 inches, the height of the key was 5 feet 3 inches; the chord of this arch was the largest known, but failing in the haunches it was taken down, and replaced by the present bridge.

Nothing is more important than the right proportioning of the key-stone, and by a reference to the several accounts already given of bridges, it will be seen how this has been regulated by practice; a twenty-sixth of the span is generally given for its depth where granite is employed.

Whatever the form given to the arch, the walls or piers that support it may either be brought up in horizontal courses, or depressed in such a manner that they gradually incline, following out the curve: a semi-circle, or semi-ellipse, requires level abutments to spring from, whilst the others should be made to incline, and have their joints and foundations radiating, or vertical to the intrados, so that the pressure they produce may be carried in a direction as nearly as possible at right angles to it: after the arch-stones are prepared and their two beds cut to their proper inclination and numbered, they are laid in their situation, so that their joints radiate vertically to the intrados; after which the curve under it, which is a portion of the arch, must be examined and worked out to its proper form, or when the centering is removed, the whole will have a crippled appearance. The exact curvature of the intrados, already drawn out at large, must be constantly referred to during the progress of setting the voussoirs, to ascertain if each is not only in its due position, but has its proportion of curvature, and its joints properly directed. Mould boards, fitted exactly to the large curve, and numbered, enable the mason to effect this portion of his work with great accuracy: when the voussoirs are not composed of single stones, the same or greater care must be taken to fit in that which is to complete the one the length of which is not sufficient. The lewis-hole, cut in the upper part of each stone, is so placed with relation to its centre of gravity, that it can be raised and lowered in its intended position without turning or twisting it round. Without this attention, it is useless for the engineer to occupy himself with the form of the curvature of an arch, for the flowing line of an ellipsis would be destroyed and rendered unsightly, if either of its numerous voussoirs were otherwise placed than in its right position: instead of a continued and regular sweep, either a polygon or broken outline would be the result; to remedy such neglect, and bring the soffite of an entire arch, of any curvature, into the state required to please the eye and satisfy it that its strength is not impaired, would oblige, after the centre was struck, the erection of a scaffold and the employment of many workmen, and after all the beautiful form first aimed at would not be produced.

The Thickness to the Abutments of Bridges. — Parent and Lahire were the first to turn their attention to the form of arches, but the nature of the thrust, and the manner in which the rupture of an arch takes place, had not been at that time sufficiently observed, and consequently they employed an hypothesis which does not agree with practice: they supposed that the joints of the voussoirs were perfectly polished, from whence it results that for the arch to support itself in equilibrio, it is necessary that the reciprocal pressures exerted by the voussoirs perpendicularly to their beds should mutually destroy each other; if such were the case, it would be easy, when the thickness of the arch at the key is given with the curve of the intrados, to determine that of the extrados, and it must be observed, that in the case where the intrados is a semicircle, we have for the extrados a curve, which is infinitely prolonged, and to which the horizontal diameter of this semicircle serves as a symptote. Hence it results that the semicircular arch could not support itself unless the first voussoir, setting off from the springing, had an infinite length; these arches then would not have any thrust, and would tend on the contrary to add to the stability of their piers. If the arch were extradossed of equal thickness, or if the voussoirs had all the same length, the equilibrium could not subsist, unless there were given to the curve of the intrados a particular form: when the thickness of the arch is very small, this form must be a reversed catenarian curve, since the arch being then considered an assemblage of heavy spheres infinitely small in contact with each other, the conditions of equilibrium are the same as those of a heavy and inextensible cord, which results are deemed of little practical utility. The first writers on this subject, wishing to prove that they were applicable, endeavoured to determine the thick-

ness of the abutments, and Bernoulli gave a solution of the problem. In the hypothesis of the perfectly polished joints, the arches where the tangent at the springing is not vertical are those only which can have a thrust; but experience proving that other arches also have one, we must recur to a supposition to determine its value. In a memoir published in 1712, in the History of the Academy of Sciences, Lahire supposes that a semicircular arch tends to disjoint at D*d*, and that the upper part D E*d* acts as a wedge to overthrow the inferior parts, sliding down on the joints of rupture, and making the lower parts turn on K*k*. According to this hypothesis, we can easily determine the effort produced by the weight of the superior part of the arch, following a direction D V perpendicular to the joint of rupture; and in expressing that this force is in equilibrio round the point K with that which results from the stability of the inferior part of the arch, we obtain an equation which gives K B, or the thickness which the pier should have to resist the thrust. It was supposed in the calculation that the arc B D was equal to half the quarter of the circle, because it was thought that the rupture of semicircular arches usually took place at an angle of 45°; but it has since been observed that the calculation of Lahire makes the thicknesses of the piers greater as they approached the joints of rupture of the summit F of the vault.

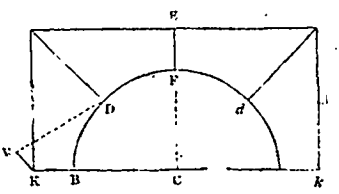


Fig. 2736.

This method of determining the thickness of the abutments of arches has been admitted by all engineers who have paid attention to this subject. Belidor has applied it to arches of different kinds, and tables have been calculated, which have appeared in the "Cours d'Architecture de Blondel," and it was supposed that in the arches described with three arcs of a circle, the joints of rupture would be at the junction of the arcs, in the "Memoires de l'Academie des Sciences" for the year 1729. Couplet adopted the same theory, and resolved, always upon the hypothesis of the joints being perfectly polished, the principal questions relative to arches: he examined also the pressure which they exercised on their centres, a subject which Pitot had already treated upon in 1726. In a second memoir printed in the year following, Couplet endeavoured to establish a theory on arches, on an entirely contrary hypothesis to that which he had previously adopted: supposing that in the fall of an arch the rubbing of the joints of the voussoirs was such that they could never slide on their beds, and that to separate themselves from each other it was necessary that their joints should open and turn round upon the edge, he made moreover an abstraction for the resistance which the adhesion of the mortar might oppose to this movement. Although this supposition, as well as the preceding, is not conformable to truth, it conducted the author to a theory approaching it: the observations and experiments which have been made since the epoch at which he wrote have taught us that, in almost all cases, the consideration of the friction was nothing in the nature of the movements of the arch, and that in these different movements, the voussoirs turned in certain places round their edges, whilst the joints tended to open and shut; but the expressions to which Couplet arrived are so complicated, and of so little value in practice, that no one has used them; the supposition on which they were established being also false, no confidence could be given to them.

A little time after the publication of the two memoirs of Couplet, Danisy repeated before the Academy at Montpellier experiments on models of arches in plaster divided into a certain number of voussoirs, and pointed out the effect of the weights with which he loaded them, and the manner in which they produced the rupture: these experiments are indicated in the "Coupe des Pierres," by Frazier, which also contains a rule the author deduced from them, and in which he attended less to exactness, than to the convenience of the workman, as, in determining the thickness of the abutment, he neglected to take into consideration the height of the piers, which nevertheless materially influences it. These experiments are the first indications of the true theory of arches; but they were made upon too small a scale, and the calculations do not appear to have been properly applied to them.

We find in the "Recueil des Savants Etrangers," for the year 1773, a memoir by Coulomb, where there is a question on the equilibrium of arches: this celebrated natural philosopher considers them successively in the hypothesis of the joints perfectly polished, and in that where the friction and adherence produced by the mortar would oppose this disjunction of the voussoirs: in the latter case, he regards first the half D E of the upper part of the arch as a body carried on an inclined plane, and, having regard to the effect of the friction and of the cohesion, gives the limits between which are found comprised the value of a horizontal force acting in the sense E*i*, which opposes itself to the sliding of the body, and supports it in the inclined plane D F. He afterwards observes that the result of the two forces which act on the portion of the arch D E must necessarily meet D F, between the

points D and F, and the second condition furnishes two new limits between which the value of the horizontal thrust should be comprised: after that, if we suppose that the friction of the joints be sufficiently considerable for the upper part not to slide on D F, the second condition of the equilibrium will

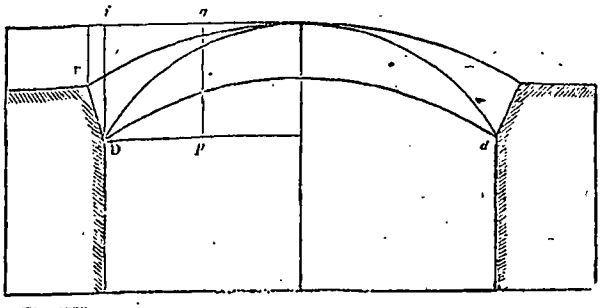


Fig. 2737.

be the only one necessary to take into consideration, and the value of the horizontal force will be found comprehended between the maximum of the expression:

$$B=\phi\frac{Dp}{Di}$$

and the minimum of the expression:

$$B=\phi\frac{lq}{Fl},$$

in which B represents that force, ϕ the weight of the portion of the vault D E, and D p and lq the horizontal distances of its centre of gravity, to the points D and F, round which it tends to turn; these maximum and minimum being taken by varying the angle formed by the joints F, D with the vertical. This analysis leaves nothing to desire, and to make it coincide with that to which we are conducted by recent experiments on the stability of arches, it is sufficient to express that the horizontal thrust of the arch, such as has been just determined, cannot displace the piers D, K, whether it tend to turn round the external edge K, or to slide horizontally on its base.

Bossut published in 1774, in the "Memoires de l'Academie des Sciences," some researches on the equilibrium of arches, in which he took up the hypothesis of the infinitely polished joints, and developed it to determine the conditions of the equilibrium of semicircular arches and of domes. He endeavoured to ascertain, after admitting the hypothesis of Lahire, the manner in which the rupture of the arch is made, and by what means its thrust is exercised against the piers; also to establish the form to be given to the external face of the pier, that it may offer equal resistance in all parts of its height.

M. de Prony in the first volume of his Hydraulic Architecture, published in 1790, after having given the different equations for establishing the thickness of the abutments, the length of the joints of the voussoirs, the form of an extradossed arch, which in the received hypothesis should be that of a catenarian curve, that the voussoirs should be in equilibrio, he introduced into the question the condition of the friction of the joints, and showed that, on account of the modification which results from this in the equation of equilibrium, it is not necessary to attribute to the horizontal joint an infinite length, as required by the first hypothesis. M. de Prony also insists on the necessity of giving to the key of an arch a sufficient thickness for it to resist the pressure it supports, and indicates the manner of determining this thickness: with a view of enabling builders to judge of the boldness of their works, he establishes a relation between the opening of an arch, and the smallest length which can be given to the key.

A memoir entitled "Dissertations sur les Degradations du Panthéon Français," published by Gauthey, contained researches on spherical vaults, in which are indicated the true methods by which the thrust of cylindrical vaults may be estimated, deduced from known observations.

M. Boistard, chief engineer of the Ponts et Chaussées, has since repeated at large, and with all the care and exactness possible, the experiments on the stability of arches, the description of which is given in a memoir placed in the school of the Ponts et Chaussées, to which is subjoined a theoretical essay on the most important conclusions to which they may lead. Such are the principal researches which have been made on the theory of semicircular arches. Several experiments upon this subject were made by M. Lecreulx, on a model of the Pont Fouchard, which was on a scale of about a sixtieth of the original, and the material employed was freestone.

Fig. 2738. shows the abutments formed of a single stone; one was 24 feet thick, the other 18 feet 6 inches: after striking the centre the equilibrium was maintained, but when a weight equal to one-twentieth part of that of the arch was added, it fell: when both

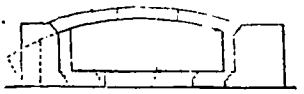


Fig. 2738.

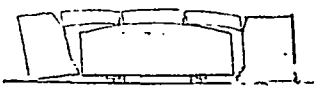


Fig. 2739.

abutments were 24 feet, and the weight was increased upon the arch, they each slid upon the platform, as shown in fig. 2739., and the three voussoirs altered their position.

Fig. 2740. shows one similar abutment to the last, and the other replaced by one 36 feet thick, formed by three stones; on striking the centre, the abutments, which was of one

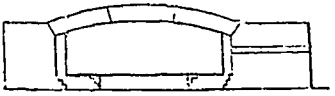


Fig. 2740.

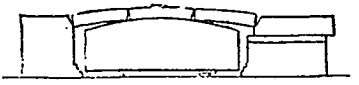


Fig. 2741.

stone, did not move; the upper portion of the other slided horizontally, whilst the lower remained stable, as in fig. 2741.

Fig. 2742., one abutment being substituted, 32 feet thick, of a single piece; the second of the same thickness, composed of four pieces, three of which were cut, with joints radiating

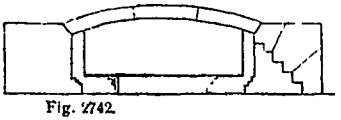


Fig. 2742.

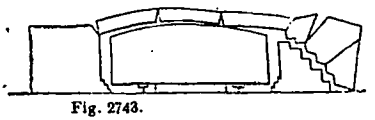


Fig. 2743.

to the centre of the arch: the abutments resisted until one-seventh of the weight of the arch was added, when it assumed the form shown in fig. 2743.

Fig. 2744. shows one abutment of a single stone, 36 feet thick, and others of 65 feet, composed of four pieces: when the centre was struck, the key sunk, and the joints opened at

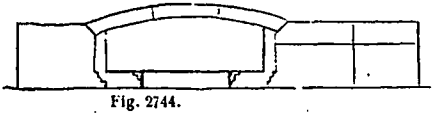


Fig. 2744.

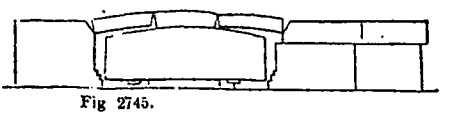


Fig 2745.

the intrados, and it remained in this position; but a trifling weight added gave it the character shown in fig. 2745.

Fig. 2746., two abutments of 36 feet, one divided into five pieces: in this case the arch supported one-fifth of its weight; it then gave way, as seen in fig. 2747.: if a resistance be

Fig. 2746.

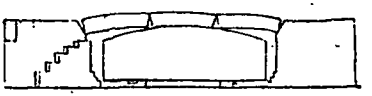


Fig. 2747.

placed beyond the abutment, composed of several pieces, the arch will support more than three-fourths of its weight without yielding, as seen in fig. 2748.

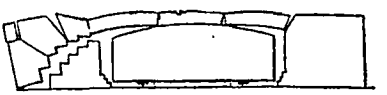


Fig. 2748.

Fig. 2749., with two arches and one pier, the first abutment formed of five pieces, 36 feet in thickness, and the other six pieces, and 72 feet thick: on adding a slight weight to the arches, the upper part of the latter slipt, and the other resisted, as in fig. 2750.

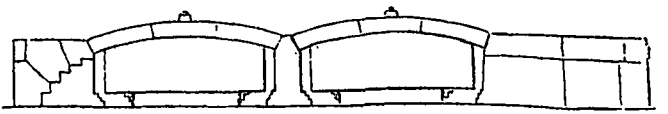


Fig. 2749.

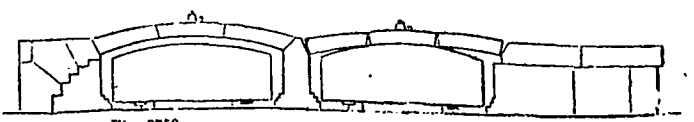


Fig. 2750.

Perronet has given in his works a description of the movements which have taken place in great arches which he constructed, both whilst their voussoirs were carried by their centres, and after the keys were placed and the centres removed; he has indicated the means of striking these centres, so as not to expose the curve of the arches to any change, and the precautions which are necessary to be taken in placing the voussoirs: the observations he has published form a complete system, and are of considerable value. It is generally remarked, he says, that the first course of the voussoirs may be placed without the assistance of the wooden centre, which only becomes necessary as they begin to slide one over the other, which happens when the bed of the joints makes an angle of 40° with the horizon: the centre then begins to carry a portion of the weight of the voussoirs; it sinks in its lower part, and when the centres are forced up, it would rise at the summit, if an opposition were not used to resist this movement, by making it support a weight more or less considerable. In the arch of Saint Edmé, at Nogent-sur-Seine (see page 265.) these effects were observed and described with the greatest care; it was struck from three centres, its span being 96 feet, and 29 feet 9 inches from the springing to the key; its thickness at the summit is 4 feet 3 inches; each half of the arch is composed of forty-seven courses of voussoirs, not comprising the key. The first twenty courses of voussoirs having been placed, the five last separated, on account of the sinking of the centre on which they rested, the joint opened $\frac{3}{4}$ inch at the extrados above the fifteenth course, and a vertical disjunction took place between the arch and the horizontal beds of the abutments, the effect of which was evident to the seventh course: in continuing the masonry, the joints closed, and the point of separation of the acting and resisting parts being carried higher by the effect of the addition of a greater number of voussoirs, the joints opened at the extrados about $\frac{3}{33}$ inch from the twenty-sixth to the thirty-first course.

At the bridge of Neuilly (see page 268.), in the arches adjacent to the abutments, the half of which is composed of fifty-six courses of voussoirs, not including the key, the joints opened successively at the extrados, on account of the advancement of the laying of the voussoirs, from $\frac{1}{8}$ to $\frac{1}{4}$ inch from the eleventh to the thirty-sixth course; analogous effects have been observed in other bridges. After the placing of the key these effects produced by the weight of the voussoirs manifest themselves in a different manner, the centres, which at first had been loaded in the lower part, inducing the summit to rise, were now charged in the middle, tending on the contrary to rise at the haunches: at the arches of the bridge at Neuilly the last joints opened at the extrados, and on each side other joints opened at the intrados, starting from the key. At the bridge of Nogent the vertical disjunction which took place between the voussoirs and the laying of the abutments almost entirely disappeared, and the last joints opened at the extrados, in the upper part of the arches, again closed. Before the striking of the centres, there had been traced on the heads of this latter bridge three right lines, one horizontal, at the summit of the arch, from above the twenty-eighth course on one side to the corresponding one on the other, and the others inclined, traced on the haunches from the extremity of the first line to the point where the joint of the seventh course meets the tangent vertical at the springing: the position of the extremities of these lines had been made with relation to fixed points, and the object was to know by the changes which should show themselves in their position and form, what would be the play of the voussoirs during the sinking. The curve of the upper line indicated a vertical sinking, which diminished uniformly from its centre to its extremities: as for the other two lines there was formed in their curve a point of inflexion at the meeting of the joint of the sixteenth and seventeenth course, which indicated, besides the vertical sinking and the closing of the joints in the upper courses down to and including the seventeenth, a closing also of the joints of the lower part, which was even carried down to the joints of the abutments.

It may be concluded from these observations, which may be repeated in all constructions of a similar kind, that the upper part does not tend to push out the lower by sliding on the joints of rupture, as was supposed by Lahire, and consequently that the result of the calculations made upon this hypothesis is erroneous: to form a just idea of the nature of the thrust, we must consider successively the two principal epochs of the construction of an arch. When the greatest number of voussoirs is placed, and we are near arriving at the key, the centre becomes considerably loaded in its upper part, because it entirely supports the weight of the arch, and it consequently undergoes a sinking, the effect of which is most sensible towards the summit: each voussoir descends in proportion to its proximity to the key, and it is evident that that cannot take place but as it turns round its inferior edge, which obliges the joint to open at its extrados; this opening is above all evident at the point where, on account of the inclination of the planes of the joints, compared to the direction of the weight, the vertical sinking is distributed more unequally in the consecutive voussoirs, and therefore in the bridge of Nogent the most open joint was found towards the twenty-sixth course.

When the key is placed and the centre is struck, the upper parts of the arch D E, *d* E, are no longer supported by their reciprocal pressure, on account of the sinking hence

produced; their common point of support is necessarily carried in E to the extrados; the joints then tend to close, as is constantly observed, and some builders add to this effect by removing wedges, which augment the solidity of the arch, at the same time that the energy of the pressure which these two parts exert upon each other is the means by which they are mutually supported. The efforts of this pressure is necessarily carried towards the abutments and the inferior parts of the arch, which it tends to overthrow, by

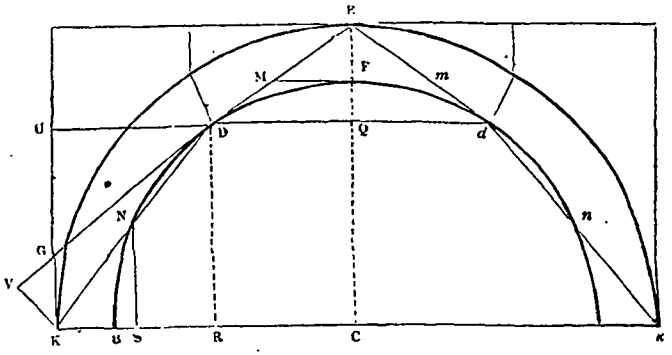


Fig. 2751.

making them turn round their exterior edges K, *k*; each half of the arch separates itself into two parts, D, *d*, which serve as points of support to the upper parts, by means of which their effort is transmitted to the abutments. These points of support are necessarily placed at the intrados: if the abutments have not sufficient stability to resist the efforts of the arch, the four parts fall down, turning round the points K, D, E, and *d*, *k*; if they are capable of supporting it, the effect of the sinking is limited to closing the joints at the extrados near the point E, to the intrados near the points *d*, D, and to make them open at the intrados near the point E, and the extrados near the points D, *d*. The position of the points D, *d*, which are called points of rupture, which it is extremely important to ascertain exactly, depends on the form of the arch, and the disposition of the weights which it supports. At the bridge of Nogent the position of the joints of rupture was indicated between the sixteenth and seventeenth course of voussoirs, by the points of inflexion of the two lower lines traced on their heads. At the bridge of Neuilly it was not possible to discover it by the same means, on account of their form, which is an arc of a circle; but it was discovered that the joints of rupture were placed between the twenty-sixth and twenty-seventh course, as it was in this place that the joint opened on the extrados.

It is seen that arches cannot fall but in proportion as the voussoirs are placed near the key, the points of rupture and the base of the abutments separating from each other by turning round their edges: the tenacity of the mortar is opposed to this effect, and this may be sufficiently great for the arch to support itself, as happens sometimes in ancient constructions, although the abutments have not their proper thickness; we cannot, however, rely on the adhesion of mortar, because its effect is only produced at the end of a certain time, and although, on leaving the arches on their centres, time may be given for the masonry to become solid, it is better not to regard the increased solidity obtained by this means, and which it would be difficult to value exactly. These observations are found to be confirmed by several arches which were in danger of falling, as well as in those which have been demolished: with regard to the latter, horizontal cuts were made in their piers, and it has been remarked that the first disjunctions appeared at the intrados towards the key; that others afterwards took place towards the haunches, where their greatest width was at the extrados, and that, in short, the upper part lowered, dividing itself into two principal parts, each overthrowing the piers opposed to it.

This theory is equally in agreement with the direct experiments made by Gauthey on this subject, who constructed semicircular arches and others for the purpose; their openings were 25½ inches; the voussoirs, 1 inch in width at the intrados, were made in wood, and worked with great exactness; he endeavoured to break the equilibrium between the thrusts of the upper parts and the stability of the lower parts, by diminishing the thickness of the abutments, or by loading the summit of the arch, and he constantly remarked that the rupture tended to operate with the circumstances already explained. These same experiments were repeated on a larger scale by M. Boistard, in arches which he constructed with much exactness in voussoirs of brick rubbed to a face, the thickness and the height of the section of which were 4¼ inches; the arches were 2·274 metres (7·458 feet) of opening,

0·22 metres (0·72 feet) in length. With these materials arches were constructed semicircularly with three centres, and others flattened a third and a fourth in the arc of a circle, the versed sine of which was the fourth, the eighth, and the seventeenth of the opening: they were constructed on a wooden centre, and their rupture took place on lowering it vertically, either when loaded at the top or when the thickness of the abutments was diminished. Each of the arches was submitted to three principal trials; in the first they were extradossed 4 inches of thickness, and as that thickness was not sufficient for them to support themselves when the centres were lowered, a certain number of voussoirs of the upper part descended vertically with it, and were carried on its summit; the two inferior parts of the arch then had the effect of two ramping arches, and divided into two parts; the last joint of each part opened at the intrados, near the upper extremity and near the springing, and the rupture appeared towards the middle, where the voussoirs did not touch the centre, and where the joints opened at the extrados.

In the second trial, where the arches were again extradossed, on each side a certain number of voussoirs of the lower part were embraced by a cord which leant on their extrados, and was extended by a weight: the pressure which this cord produced on the last voussoir opposed their separation, which the upper parts of the arch tended to produce; and it was constantly observed that if the weight occasioned by the tension of the two cords was not sufficient for the equilibrium, the arch broke by opening at the intrados, near the key and near the springing, where the last voussoir tended to swing round its external edge, and at the extrados on the haunches. Secondly, that where the weight was sufficient to maintain the equilibrium, the joints opened in the same manner, on account of the inevitable sinking, but that the action of the weights tending to tighten them, they opened and shut alternately by an oscillating movement, in which the parts of the arch turned alternately round the points of support which the edges of the consecutive voussoirs presented to them. Thirdly, that when the tension of the cord was sufficiently considerable for the pressure which it exerted over the inferior parts of the arch to be capable of raising up the upper parts, the same effects were manifested in a contrary sense, that is to say, that the arch broke at the key, opening at the extrados, and at the haunches it opened at the intrados, and at the springing the last voussoir turned round the interior edge. When the arches were raised on piers, the effects were exactly similar, except that the piers became a body with the inferior parts of the arch, which in falling over tended to turn round the external edge of the base of the piers, instead of that of the voussoir placed at the springing.

In the third trial abutments were established, and the haunches of the arch filled in with masonry, levelled at the summit, where this vault was 4 inches in thickness. When the stability of the abutments was sufficient to resist the thrust, the arch preserved its primitive figure after striking the centre; when the weight of the upper part was increased, the arch broke as usual, and the position of the joints of rupture in the haunches was determined by the value of the weight, by the manner in which it was distributed on the summit of the arch, and by the height of piers on which this arch was sometimes raised; it has generally been observed that when the arches were not raised on piers, the rupture tended towards the angle of 30° of the half circle described by the semicircle, or towards the angle of 50° of the little arc described in the arch struck with three arcs of a circle; the point of rupture tended to rise when the height of the piers was augmented, and when the summit of the arch was more loaded.

All these experiments confirm the principle already established on the nature of the movement of arches, from whence it results that in the research for the conditions of their equilibrium, we may without sensible error consider them as a system of four levers, K D, D E, E d, d K, each loaded with the respective weights of the parts of arches which correspond with them (see fig. 2737.), and being able to turn round the points of support K, D, E, d, k, where they form turning joints; the position of the points d, D depend for each particular case on the figure of the arch, and the distribution of the weights with which it is loaded.

The same conclusion is applicable to the arcs of a circle, and to the flat arch, where the arch and its piers form a system, the nature of which is similar: we must here remark with regard to the figure of this arch, that the position of the joints of rupture is found naturally fixed at the springings, unless it be very slightly extradossed, or the versed sine of the arc of the circle according to which it is described be almost equal to the radius. The experiments of M. Boistard proved that an arc, the versed sine of which is the quarter of the chord, has its joints of rupture at the springing, when the haunches are filled with masonry.

The application of the calculation to the preceding theory presents no difficulty: the points N, M, m, n, being those where the levers are met by the verticals which pass by the centres of gravity of the parts corresponding to the arch, we may suppose that these levers are loaded in these points with four weights equal to those of the masonry, and we must

determine the relation which ought to exist between the weights and the direction of the levers, in order that the equilibrium may be maintained. Let us consider the half of the arch divided into two symmetrical parts by the axis E C, and let us suppose, first, that the point D is fixed: call μ the weight applied in M. The system will not be changed in substituting for it two other weights, the one applied in E, and represented by $\mu\frac{FQ}{EQ}$, the other applied in D, and represented by $\frac{EF}{EQ}$. The point E will then be loaded with a weight equal to $2\mu\frac{FQ}{EQ}$, and there will result from it in the sense of the lever E D a pressure represented by $\mu\frac{FQ}{EQ}\cdot\frac{ED}{EQ}$, and which, if the point D were really fixed, would be destroyed by its resistance, as well as the effect of the vertical force, $\mu\frac{EF}{EQ}$, which is applied at the same point: but this point D being situated at the extremity of another lever, the point of support of which is in K, and which is loaded at the point N with a new weight, represented by γ, we must for the equilibrium take the momentum of these different forces with relation to the point K as null, which will give the equation,

$$\mu\frac{FQ}{EQ}\cdot\frac{ED}{EQ}\,KV=\mu\frac{EF}{EQ}\,KR+\nu\,KS,$$

K V being a perpendicular lowered from the point K on the line E D prolonged, and K S and K R being the horizontal distances from the point K to the point N and to the point D. We have,

$$KV=\frac{KU.DQ-DU.EQ}{ED}$$

and in substituting this value in the preceding equation it becomes,

$$\mu\frac{FQ}{EQ}\cdot\frac{DQ}{EQ}KU=\mu\,KR+\nu KS;$$

and if we desire that the system have stability we must have,

$$\mu\frac{FQ}{EQ}\cdot\frac{DQ}{EQ}KU<\mu\,KR+\nu KS.$$

The value of the thrust, and consequently the thickness to be given to the abutments, augments with the value of F Q, that is to say, when the centre of gravity of the upper parts of the vault approaches the summit; it is the same with the horizontal pressure which the two parts of the arch exert on each other, in the case of the equilibrium, as is indicated by the form of its expression, which is

$$\mu\frac{FQ}{EQ}\cdot\frac{DQ}{EQ}.$$

It is to be remarked, with M. Boistard, that there has been a mistake hitherto, in endeavouring to make the sinking of an arch depend on the diminution of the length of the curve of the intrados: this sinking evidently depends on the shortening of the curve D E *d*, fig. 2737., which unites the points by which the voussoirs carry each other near the joints of rupture, and which may also be considered as the place of the points of support of the intermediate voussoirs: the nature of this curve is not easy to be determined, but we may in the application regard it, without any great error, as being of the same kind with the curve of the intrados.

Application of the Theory to the determining of the Thickness of the Abutments. — This equation

$$\mu\frac{FQ}{EQ}\cdot\frac{DQ}{EQ}\,ku=\mu\,KR+\nu KS$$

contains all that is necessary to resolve this question; and it is now only required to find a value of B K which shall satisfy this equation, or rather which shall render the second member a little larger than the first, in order that the arch should have the necessary stability: this is supposing that the positions of the points of rupture D, *d* is known *d-priori*, which is not generally the case; we must then begin by determining it. And we shall observe that these points must be so placed that the momentum of the force which tends to overthrow the lower part be the greatest possible with regard to that of the forces which tend to retain it in its position. We must then seek the value of the arc B D, which corresponds to the *maximum* of the expression

$$\frac{\mu\frac{FQ}{EQ}\cdot\frac{DQ}{EQ}ku}{\mu\,KR+\nu\,KS}$$

The calculation is almost impracticable for semicircular arches, on account of the various quantities which the nature of the circle introduces in this formula, and it becomes totally so, for the arch composed of several arcs; we must therefore have recourse to an indirect method, which consists in making different hypotheses on the position of the point D, and in determining for each the corresponding value of B K, from *examples of known bridges*, whose form approaches that of the one projected; it is evident, moreover, that the greatest value which we could find for B K will be that which we must take into consideration, and that the positions of the joints of rupture will be determined by the correspondent value of the arc B D.

The following table contains the result of this calculation for those vaults most frequently used; we have supposed that the opening of these vaults was 20 metres, that the thickness at the key was 1 metre, that the upper part was extradossed level.

	Thickness of the Abutments. Metres.	Position of the Points of Rupture. Degrees.
Semicircular arches - - - - -	- 0·45	27
Arches struck from three centres depressed one-third	- 0·66	45
depressed one quarter of the span -	- 0·82	54
Arch of a circle of 60 degrees raised upon piers 5 metres high - - - - - -	- 2 95	0

The calculation has given for the arches of the three centres flattened a quarter a joint of rupture placed differently to that which experiment has indicated for the bridge of Neuilly; this joint of rupture will be here found at the 16th and 17th course of voussoirs, and we have before observed that it was above the 26th course; this difference depends on the supposition in the calculation that the masonry of the haunches was raised, which was not the case with the bridge at Neuilly at the moment of striking the centres, and in which the position of the joint of rupture was decided.

The addition of this masonry necessarily changes the position, and the joints of rupture, as shown in the experiments of M. Boistard, are the more elevated, as the summit of the arch is more loaded with relation to the haunches. The results of the calculation agree exactly with the observations made at the bridge of Nogent, where the masonry of the haunches was constructed when the centres were struck.

The results comprised in the table are below the ordinary dimensions, and the theory indicates thicknesses less considerable than those which have hitherto been thought necessary for the abutments of bridges.

The preceding calculations suppose that the different portions of the arch form solid masses, the parts of which are perfectly united together, and cannot undergo any sinking; it supposes also that the abutments are established on a base entirely incompressible, and that in the fall of the arch these abutments would turn, without disjointing, round their exterior edge; these suppositions are in general far removed from the truth. The fall of a bridge could scarcely happen without some disjunction taking place on the abutments, however great the care with which they may have been constructed; and even should there be none, these abutments could not turn round their external edge, where the stones would necessarily be crushed under the effort they would have to support, an effort which should be on that account spread over a sufficiently great surface: as for the incompressibility of the foundations, this condition is very difficult to obtain exactly, above all when the masonry of the walls is not established on a platform placed on piles; and we cannot doubt that the fall of the greater number of bridges must be attributed to the movements which have manifested themselves in the points of support on which they were carried; but as the foundation approaches to incompressibility, in proportion as the effort which it supports is distributed on a greater surface, the constructor is obliged, in order to unite physical circumstances to analytical hypothesis, to increase the dimensions of the points of support. The difference existing between the methods adopted by practice and theory may be thus accounted for, and it is easy to conclude that we must augment the points of support: it is not easy to determine the value of this augmentation; it depends evidently on the nature of the materials and the kind of construction used, on the nature and solidity, more or less great, of the foundation, and of the other particular circumstances relative to the projected bridge. It is prudent to adopt greater thicknesses than those indicated in the preceding table, or than can be calculated by means of the same theory; but as this theory in its application to very flattened arches gives very considerable thicknesses, we have sought and succeeded by different means, as will be seen below, to reduce this enormous mass of masonry without any loss of its resisting force. The arches may be raised on piers, and then the positions of the points of rupture change, as well as the thickness of the abutments, which becomes more considerable; it is indispensable to determine its value in each particular case. We suppose then, conformably to the results of the experiments already alluded to, that the piers form only one single body with the inferior part of the arch, and that in the rupture it turns round its external edge: some have thought that a rupture might take place in

some point of the height of the pier, and they have in consequence endeavoured to determine what form it ought to have to present everywhere an equal resistance; the solution of this problem is difficult, on account of the calculations to which it would lead; it is besides of no practical value.

We have hitherto supposed that the rupture of arches could not take place unless the abutments should turn round their exterior edge; there might, however, happen a horizontal disjunction, when the upper part would slide over the lower. The resistance which the abutment opposes to this movement depends on the weight of the upper parts, and on the manner in which the beds are united to each other; the friction and the adhesion of the mortars being here the two principal means of solidity, the value of which effect has been calculated.

M. Boistard published in 1804 some experiments on this subject, the results of which were that the adhesion of the mortar is proportioned to the surface; that the time after which the stones are detached has little influence on the value of this adhesion, which is almost as great after the first month as after years. It may be valued as 6960 kilogrammes for a square metre for mortar composed of lime and sand, and 3700 for mortar of lime and cement; these values only being considered as proximate results because they necessarily vary, on account of the quality of the material of which the mortar is composed. The great superiority of mortar made with sand over that of cement, which at the end of a year is increased, does not exist when employed under water; in this latter case the cement contracts quickly into a strong consistence, which is not the same with the other.

With regard to the friction, M. Boistard has equally endeavoured to discover its effects, and found that its relation to the pressure is constant, and that in taking the least value given by these experiments, this relation for a stone indented or picked, gliding on a similar stone, or what is the same, on a surface of mortar hardened by the air, was equal to 0·76, or about $\frac{3}{4}$.

Considering the equilibrium of arches in this point of view, we find for the abutments thicknesses different to those which are indicated in the preceding table; the equation of equilibrium is then

$$\mu \frac{FQ}{EQ} \cdot \frac{DQ}{EQ} = 0{\cdot}76\,(\mu + \nu) + 6960\ K\,R.$$

The following table contains these new results applied to arches extradossed to the level, the opening of which is 20 metres, and the thickness of the key one metre: we have supposed that the disjunction always took place at the level of the springing, and no account has been taken of the vertical pressure resulting from the weight of the upper part of the vaults, which reduces the preceding equation to

$$\mu \frac{FQ}{EQ} \cdot \frac{DQ}{EQ} = 0{\cdot}76 + 6960\ K\,R.$$

The masonry is supposed to be 2600 kilogrammes per cube metre.

	Thickness of the Abutments. Metres.	Position of the Points of Rupture. Degrees.
Semicircular arches - - - -	1·32	14
Arches struck from three centres as before -	1·62	32
depressed one-fourth - -	2·24	41
Arc of a circle of 60 degrees - - -	3·09	0

These last results are again below the dimensions which engineers have generally adopted, but they, however, approach nearer to them than those of the former table. According to this manner of calculating the equilibrium of arches, there is less of hypothesis than in the first, and if it be observed that the values of the second table suppose that the arches have remained long enough on their centres for the mortar to have acquired a tenacity similar to that which it presented in the experiments just given, which scarcely ever happens, as it dries very slowly in the interior of the masses of masonry, we shall be convinced of the necessity of increasing them still more, and of thus approaching nearer to the results of practice.

We have allowed a little more thickness to arches than is generally given, which tends to favour the acting power: no account is taken of the beds of sand or earth, or of the pavement with which the arches are generally charged, nor of the difference of specific weights of the various kinds of masonry; it would be easy to introduce these objects in detail in the calculations, but we are convinced we should not then obtain for the thickness of the abutments values sensibly different from those which have been given.

The arches of the arc of a circle require the thickness of the abutments much more considerable than others, and these thicknesses would be still greater, if the arch, which we have supposed described by an arc of 60 degrees, was more flattened, as in many bridges. The first engineers who raised arches of this form opposed to their great thrust

very thick abutments, but it is evident that very flattened arches tend principally not to overthrow their abutments, but to produce a horizontal disjunction in their piers, and cause their upper parts to slide. It results from hence that the mass of the abutments situated below the point where this disjunction would take place is scarcely of any utility to the solidity of the arch, and only serves to support the upper part, which alone resists the thrust efficiently; consequently means have been sought to avoid the construction of this mass, which occasions a useless expense. Among the plans proposed for this object are the two following: in the first the abutment is only an ordinary wall, behind which the arch is prolonged, and abuts against a platform supported by inclined piers; in the second, there is substituted for the mass of the abutment, walls constructed in the prolonging of the heads, which support an arch, the summit of which is placed a little below the level of the springing of the main arch; this latter method appears to unite all the advantages which can be obtained in such constructions.

It has also been the practice to incline the platform of the foundations, as well as the beds of the masonry, to the side of the arch to be supported; and there is no doubt that by means of this arrangement, the mass of the abutment is considerably diminished: it would also be very advantageous to distribute in the interior of the masonry rough stones placed upright, which should bind the beds together, and contribute effectually to prevent disjunctions.

In all that has preceded, we have supposed that the haunches of the arches were filled in with masonry, levelled even with the summit of the curve of the intrados, or following a slight inclination from this summit; it does not appear necessary to fill the haunches of an arch entirely in this manner, which augments the expense, as well as the load it must support: if the haunches be filled with earth or gravel, besides the load being very little less, the arch would be exposed to dangerous actions when these matters should be penetrated and diluted by the water which would filter through them. To prevent these inconveniences, it is advantageous, conformable to a custom generally practised, after having levelled the masonry of the haunches to an inclination towards the piers and the abutments, to a height sufficient to ensure the equilibrium of the arch, to raise on this masonry vertical walls parallel with the heads, to which from 18 inches to 3 feet in thickness may be given, placing them 2 feet 3 inches apart: the intervals of these walls remain void, and are covered with landings of stone or small arches, in order that they may have little thrust, and on which the pavement rests: care is moreover taken to contrive at the foot of the walls, or in the masonry which supports them, small openings, by means of which the water which would penetrate the haunches may be conducted to a single point, whence it runs away by a pipe placed across the voussoirs. In adopting an arrangement of this kind, passages may be reserved for the convenience of viewing the construction, and making the necessary reparations, to prevent the changes which time might produce in the masonry of the arch: where, however, void spaces exist in the haunches of the arches of a bridge, provision must be made for an accident which might take place, by a total immersion of these arches in the water. Bridges constructed in mountainous countries, on rivers or torrents subject to great floods, or near the sea, where the tide rises to a great height, are exposed to the chance of the level of the water surmounting the summit of the bridge, or even rising above the pavement; in this case it might happen, that on account of the voids left in the haunches, the weight of the construction would become inferior to that of the volume of water it would displace, and would then be exposed to be vertically raised and thrown down by the current, if the difference of the two weights were sufficiently great to surmount the forces of adhesion which would be opposed to this movement.

The loss of weight undergone by masonry plunged in the water should always be taken into consideration; regard should above all be paid to it when the dimensions of the piers of a bridge are regulated, with the intention of rendering them capable of serving as abutments, and of resisting the thrust of the arches they support.

Thickness of Piers. — The piers of bridges may be considered under two principal points of view; as destined to carry the weight of the arches, or to serve as abutments to resist their thrust. In ancient works they are always of a considerable thickness, and the bridges of Vicenza and Padua are almost the only exceptions from this practice.

Bridges of the middle ages, like the ancient, are constructed on piers thicker than would be necessary for the uses of an abutment: when the engineers submitted the thrusts of arches to calculation, and determined according to the hypothesis of Lahire the thickness necessary for the abutments, they thought that the piers should have the same thickness; and it was on this principle that the greater number of large bridges were constructed in the last century, whether in France or the other countries of Europe. The piers of the bridges of Blois, Saumur, Orleans, Moulins, Tours, Westminster, &c., were thick enough to serve as abutments, and the vaults were always centred one after the other: it would, without doubt, have been imprudent to expose bridges, composed of so great a number of arches, to be entirely overthrown by the failing of one of the piers.

But when, at the end of the last century, it became the custom to erect large arches struck from three or more centres, or those of the arc of a circle of one great radius, the practice of giving a thickness to the piers sufficient to resist the thrust of the arches was abandoned: for had it been adhered to, it would have been necessary to construct enormous piers, which, with the inconvenience of giving to the bridge an exceedingly heavy appearance, would have added the more important one of considerable expense, and much obstruction to the passage of the water. This latter is the principal objection against the piers being thick; the resistance which they oppose to the current, and the contraction which they cause, depending in great measure on their width. Supposing all other things equal, a bridge in which the piers are very thick would have a greater inclination to fall than one in which they are small; and for this reason, that it is necessary to augment the surface of the water-way, and consequently the length of the bridge: but the importance of this objection is diminished by observing, that when the dimensions of a pier are considerable, it is difficult for it to be carried away by a single flood, and it is generally possible to arrest the progress of the damage: a narrow pier does not present the same properties, unless it is carried on large footings, and the advantage in the point of economy is almost nothing, as the saving in the masonry is of little consequence, either in the piers or in the foundation, on account of the wide sets-off on which it is necessary to place them; but there is a considerable increase in the expense of the centres, as all the arches must be centred at the same time, instead of the timber employed in the two first arches serving for all the others; this inconvenience is always important, and it will become more so, as the scarcity of timber is more felt. In cases in which there is no danger in carrying the arches on very thin piers, as when established on a rock, and there can be no fear of either being carried away, the increase of the price of the centres may oblige a total rejection of the use of piers, and a proscription consequently of very flattened arches, which absolutely require them. Arches composed of the arcs of a circle flattened very much should always be carried on piers of little thickness, and one of these arrangements necessarily induces the other. The inconvenience resulting from the use of piers is thus united to the other reasons opposed to the general adoption of very flat arches for the construction of bridges. When we cannot give to all the piers the thickness they should have for the office of abutments, and when the great length of the bridge and the nature of the ground create some alarm for the solidity of the edifice, an arrangement may be adopted which would diminish the dangers resulting from the use of thin piers.

Bridges are divided into several parts, by constructing at intervals piers capable of supporting the thrust of the arches; then, if an intermediate pier be carried away, it will certainly induce the fall of some arches, but there will not be a necessity for reconstructing the whole bridge: if the bridge were established on one general platform, there would be no danger of accident; nevertheless as it may happen that some part of the platform may be carried away, it is proper to place the resistance of the piers in equilibrio with the thrust.

When the piers serve as abutments, their thickness is determined after the principles already shown; when their object is only to carry the weight of the arches, the resistance of the stone with which they are constructed is the principal consideration to which attention must be paid, and the only one which can be submitted to calculation; it leads to dimensions much below those in use. M. Perronet has remarked that the piers of the bridge at Neuilly would support the mass with which they are charged, if their thickness were reduced to 13 inches: he admitted certainly that the stone would then carry a weight under which it was crushed in a previous experiment; these piers are about 14 feet in thickness. According to this example, we must not determine the thickness of a pier with relation only to the strength of the stone, but also to various circumstances which it is not possible to submit to calculation, such as the nature of the construction, which may be entirely in freestone, or some part in moellon or rubble (rough stone); the force of the shocks to which the pier is exposed either from the ice, from trees, or other bodies which the river may carry down, and above all in the manner in which the pier has its foundations laid. There is no doubt that when the considerable weight which a pier has to support is spread over a great surface, more confidence should be felt in its foundation, whether in relation to the accidents, which are less dangerous and more easy to repair, or to the unequal settlements which may be manifested in it; and for that reason we cannot dispense with a large base for a pier the body of which is not of great thickness.

The form of piers, and above all that of their starlings, is important, and when the piers are very large, have great influence on the solidity and duration of a bridge; when their form is imperfect, it is one of the causes of the destruction which manifests itself, and always increases that which may arise from others. It appears from the first view, that if the water-way of a bridge is regulated in such a manner that the relation between the resistance of the soil and the mean velocity of the current be not sensibly

altered, it is impossible that any damage can take place, and this would be true if the mean velocity were distributed uniformly throughout the mass of the waters to which the bridge gives passage. But the obstacles which the piers and the springing of the arches oppose to the current injure that equal partition of the velocity, and whilst very rapid currents are formed, in other places the water turns and returns on itself; it is then important to give to piers the form the most proper to prevent these effects, the consequences of which are often dangerous.

In the piers of ancient bridges the starlings are generally half a circle, or a rectilineal triangle, but modern engineers have rounded the angles formed by the faces of the starlings and the body of the pier. There are some bridges built in the middle ages where the starlings have been entirely suppressed, and the piers terminated parallelly at the heads; this latter arrangement is most effective: when the current strikes against the starling of a pier, the water rises to meet it, the dash which tends to shake the starling is obliged to divide, and produces two oblique currents, which turn aside from the lateral faces of the pier, against which there only remains a dead water; these two currents narrow the principal run, by forming with those produced by the neighbouring piers little shoals, where the water flows less quick towards the edges than in the centre, because it has lost some of its rapidity against the obstacle which it meets with, and although the rapidity of the current be generally greater in the middle of the arch than at the shoulder of the pier, that part is not less exposed to it, on account of the falls and eddies which are formed there, and which attack the ground and cause the wearing away: all these effects, which are produced whatever be the form of the pier, are more evident as the faces struck by the current are more directly opposed to it. When water is introduced into a canal narrower than that where it first ran, the rapidity must augment by the effect of the diminution of the section, if the entrance into the narrow canal be not widened; and if the section diminish suddenly there is necessarily a contraction, which obliges the current to take a velocity greater than the diminution of the section requires: it is then important to render this contraction as small as possible, and this is the more essential as by it may be avoided the fall which it occasions to the shoulder of the pier, and which is the cause of the undermining: with this view we have endeavoured to compare the effects of the contraction for piers of different forms, in the experiments of which we are about to give an account, after having referred to some researches made on the subject.

We find in "Recherches sur la Construction la plus avantageuse des Digues," by MM. Bossut and Viallet, that problem resolved which has for its object to determine the proper form for the head of a jetty, and the starling of a pier subject to the same conditions; it is equally necessary to defend these structures against the action of the fluid which continually strikes against them, and it appears that the form proper to the one is equally so to the other. M. Bossut supposes that each face of the head of the jetty is struck by threads of the fluid (small currents), the directions of which are parallel, and the rapidity equal; he then seeks, according to a general theory of the shock of fluids, the form for the base of each face, in order that this shock may be the least possible; he finds that the right line resolves the problem, and that if the base be a triangle, it should be an isosceles, the two equal angles of which would be 45°. This solution is subject to many difficulties, as it appears unnecessary that the head of a jetty or the starling of a pier should receive any shock from the current, because there is no fear that it would displace the mass entirely: this must be taken into consideration if the subject were the prow of a vessel, but when the facing of the head of a jetty is well constructed, unless the water undermines it, it never can be carried away, and it is only essential to guard against this latter effect.

M. Garipuy, in a manuscript preserved in the Ecole des Ponts et Chaussées, has endeavoured to modify the triangular form generally given to starlings, so as to obtain from the fluid an equal pressure over the whole length of their faces; as the fluid accelerates its movement a little, going round the length of the starling, it follows from the ordinary theory on the resistance of fluids, that each face should be slightly convex; the form which is obtained in this manner differs very little from the triangle, and it is not under that point of view we must consider the question. We will pass over similar theories, to arrive at that which M. Dubuat has given in his Principles of Hydraulics: he thought that the essential object was to prevent the contraction and the undermining which is its consequence, and which always manifests itself when a current undergoes a sudden change in its section.

Call V the primitive mean rapidity of the current, v the mean rapidity resulting from the diminution of the section, A and a the corresponding widths of the bed, I the inclination by metre of the river, if no contraction be formed, we shall evidently have $v = \frac{A}{a} V$.* The height due to the rapidity V is $\frac{V^2}{2g}$; and if the water had acquired this rapidity in flowing over an inclined plane, where it had not met with any obstacle, it

should have flowed over a space equal to $\frac{V^2}{2gI}$; if we suppose that it continues in the same manner to accelerate its movement, it must, to require the rapidity v, flow over a space equal to $\frac{A^2}{a^2}\cdot\frac{V^2}{2gI}$. The length of the narrowing will then be represented by $\frac{V^2}{2gI}\left(\frac{A^2}{a^2}-1\right)$; and to have the intermediate widths between A and a, it will be sufficient to remark that the point where the width of the section is equal to x should be situated at a distance $\frac{V^2}{2gI}\left(\frac{A^2}{x^2}-1\right)$ from the point where that width is equal to A.

The preceding analysis gives the means of enabling a current to pass from a greater section into a smaller, without the inclination being altered, or without any fall or contraction being formed; and although no account is here taken of the resistance produced by friction, this want of exactness cannot produce any sensible errors, when the section is considerable: but these results cannot be applied to the form of the starlings of piers, because in the more ordinary cases it is necessary to give them an excessive length, and to render their angle very acute; the projection of a starling being limited, we cannot avoid the change of the section being made more rapidly than should be for the fall to remain the same, and all that can be done is to give to the faces of the starlings the least disadvantageous forms possible. To obtain this it will be sufficient to bring together the ordinates of the curve, previously determined for the form of the narrowing, so as that the distance $\frac{V^2}{2gI}\left(\frac{A^2}{a^2}-1\right)$ between the points, where the width of the sections is A and a, is equal to the portion of the length of the pier to which a curvilinear form is to be given. The principle of the solution is not satisfactory, as we may remark, according to the construction which results from it, that the curve of the starling will not be tangent to the direction of the flanks of the pier; nevertheless it appears that to prevent as much as possible all contraction in the current to the passage of the arches, it is necessary that the surface of the starling should not form an angle with the lateral face of the pier, but should be, on the contrary, traced in the prolongation of that face. The condition here proposed is that the velocity of the water should only augment in insensible degrees, and that from the effect of the figure of the starlings, the small threads of the stream should be conducted, so that they enter under the arches, in directions parallel to the flanks of the pier, and not flow from the flanks in such a manner as to increase that contraction of the current which results from the pier. This condition would be satisfied by giving to the sides of the starling a convex curve tangent to the sides of the pier, by which the starling will be prolonged, and the sides rendered more acute; the nature of the curve does not appear to be of great importance.

When determining the best form to be given to piers, we must always bear in mind that when they are totally immersed in water they will lose $\frac{3}{4}$ of their weight; and when we are obliged to place the bridge with a considerable obliquity to the current of the stream, we produce an obstruction which varies with the cosine of the angle of obliquity, and, consequently, the additional head is as the versed sine of that angle: but if the banks of the river are parallel lines, the water-way under the bridge will increase as the secant of the angle of obliquity, or inversely as the cosine.

The effect of the gyration at the shoulders of piers deserves also some notice, as it often causes their entire destruction; and the beds of rivers being all porous, the springs work through them, with a force equal to a pressure of the whole depth of the river: wherever there is a void or means for the escape of such a spring or source, its force or pressure upwards will act against any construction that comes within its influence, and wherever such a void extends to the depth of 4 or 5 feet, it is capable of lifting up an enormous weight: such a force was exerted upon the floor of the dock constructed by Smeaton at Ramsgate harbour: that celebrated engineer found that the natural springs rose in the chalk bed, and issued with such violence as to break the paving-stone with which the area was covered. Stones weighing a ton and a half, laid down at Plymouth, with a wall 100 feet in length, were hoisted up and overthrown by a similar force.

However necessary it may be to give to the piers the most proper form to prevent too great a contraction, this condition is not the only one to which regard must be paid: we must endeavour to protect them from the shocks of ice, from floats of timber and boats, and this can only be effected by giving great solidity to the starlings, taking care to make their projecting angle not too acute, which would subject it to wearing away, or blunt the angle too much, which would render it less capable of opposing the masses of ice: to avoid the contraction, it is indispensable to make the starlings very long and terminating in a point; it is thus impossible to satisfy at the same time the two conditions; and as, according to peculiar circumstances, it may be essential to have regard

to one or the other condition, that form must be selected which is most proper to produce the result required: the following experiments will enable engineers to make this choice with a sufficient knowledge of the subject.

These were made by means of a rectangular canal between boards of 50 centimetres in length, in which were placed models of piers, 15 centimetres in thickness, and where the water flowed about 40 millimetres in height. By means of a fall, velocity was given to the fluid of about 3 metres 9 centimetres per second, which is about that of great rivers in floods: care was taken to observe all the circumstances of the contraction, and the eddies and currents formed were accurately measured. The first experiment (fig. 2752.) was made on a pier, the starling of which was rectangular; the eddy formed before the pier presented a species of band, A, nearly circular, which was raised 34 millimetres above the level of the water, falling at the angle of the shoulder almost vertical. The length of the faces of the sides of the pier exhibited two other currents, B, C, uniformly inclined, and which were only real at the surface; below, the water, from the rapidity due to the fall of the eddy, formed a stream both rapid and dangerous: when two abutments were substituted for the pier, two similar bands were produced, which met each other in the centre of the arch, where they reciprocally crossed: below the figure the profile of the water taken in different parts is traced, which the letters indicate.

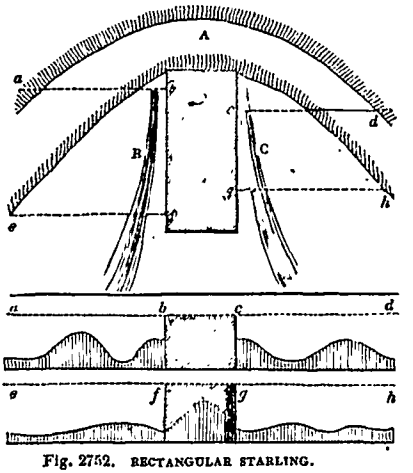


Fig. 2752. RECTANGULAR STARLING.

In the second experiment, fig. 2753., the starling of the pier was a triangle, the projecting angle being a right one; it did not form so great an obstacle as the rectangle, nevertheless the eddy rose as high: the two currents established against the flanks of the pier were much less strong, but the fall formed at the side of the shoulder was as deep, and more dangerous; the current before the eddy became a species of sheet where the water fell, returning on itself, as seen by the section.

The third experiment, fig. 2754., was made on a pier the starling of which was a half-circle: the eddy rose nearly the same height as in the preceding, but it was not so wide; it formed two currents, the first, A, followed in gentle inclination along the faces of the pier; the second, B, appeared to be produced by the opposition of the first, and neither of the two formed a fall against the pier; the water rose before the pier above bridge, but in the middle of the

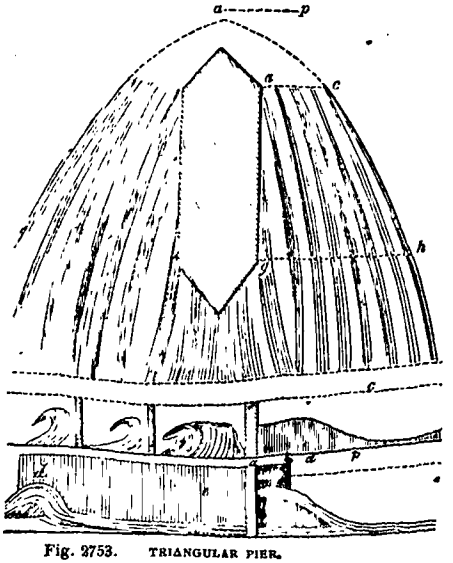


Fig. 2753. TRIANGULAR PIER.

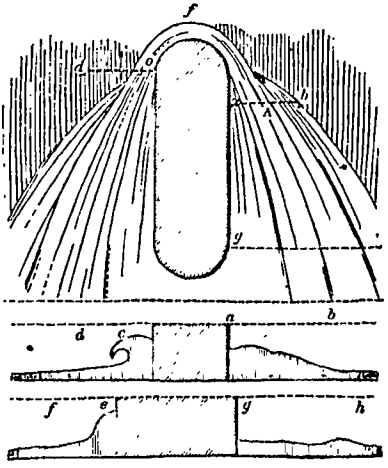


Fig. 2754. SEMICIRCULAR STARLING.

arch it evidently preserved its level, and only increased in rapidity in proportion as the principal current was narrowed by the two currents resulting from the eddy.

The fourth experiment, fig. 2755., was made on a starling, the base of which was an equilateral triangle; the same effects were remarked as in the two first, but they were not so evident; the height of the eddy was not so much, and the lateral currents diverged less; the fall, although less, still subsisted at the shoulder; the small letters on the several diagrams show the situation where the sections below were taken.

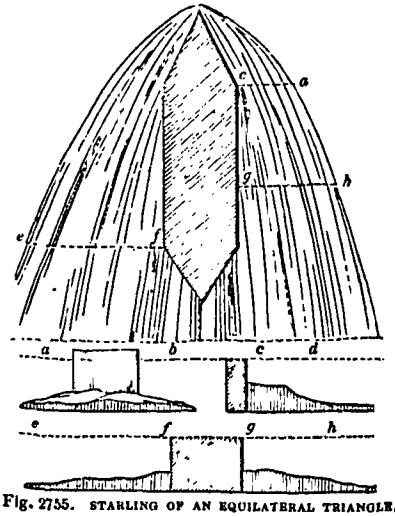


Fig. 2755. STARLING OF AN EQUILATERAL TRIANGLE.

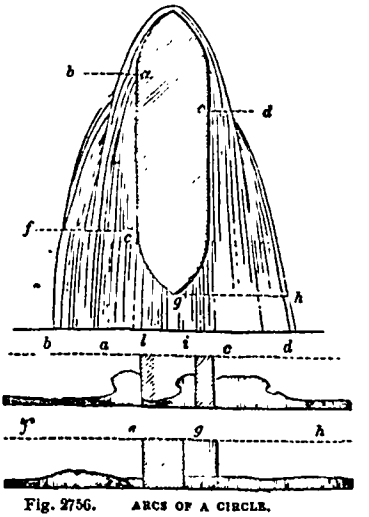


Fig. 2756. ARCS OF A CIRCLE.

The two sides of the base of the starling were formed in the fifth experiment, fig. 2756., by two arcs of a circle equal to a sixth of the circumference, described on the sides of an equilateral triangle; no cataract was formed at the shoulder: along the faces of the pier the current took an inclination which extended below bridge; there was produced on each side, as in the semicircular starling, a second current, which did not commence so soon, nor rise at first to so great a height, but which was as considerable on leaving the arch; the eddy did not rise quite so much, but the water equally fell in a sheet.

In the sixth experiment, fig. 2757., the form of the pier was that of an ellipsis, the small diameter of which was the fourth of the large one; the water rose much less before the pier than in the preceding experiments, and the lateral currents had a uniform inclination along its faces; the second current was relatively more considerable, and even became higher than the first, with which it was confounded on leaving the arch: both extended to a less width.

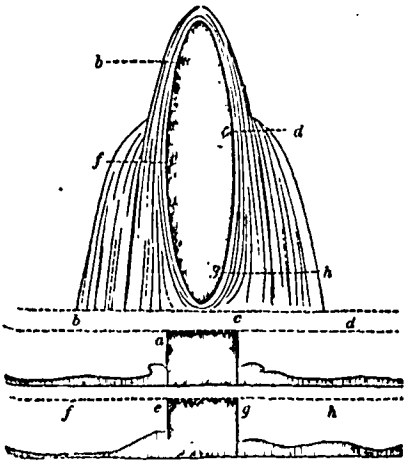


Fig. 2757. ELLIPTICAL PIER.

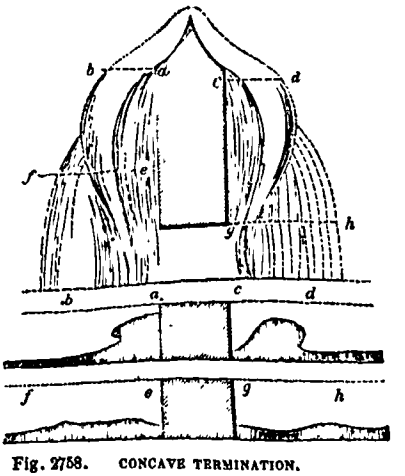


Fig. 2758. CONCAVE TERMINATION.

The seventh experiment, fig. 2758. was made on a pier, the base of the starling of which was a concave mixtilinear triangle. Starlings of this form are not generally applied to piers,

but use has sometimes been made of them to bind together the abutments with the walls of the shoulder. It is doubtless the most dangerous of all: setting off from the starling, the water rose considerably as far as the angle of the shoulder, where it formed a fall stronger than in all the other experiments, and the bottom of which was lower than the general level of the current: the lateral current, obliged to turn itself, was accompanied on each side by two others; the one joining the pier was weak, the other, but little elevated at first, soon acquired more volume, because it was raised by the principal current, and was not lowered but at a considerable distance down the river.

The eighth experiment, fig 2759. The starling of the pier had the same form as fig. 2758., but we have supposed here the springing of the arches surmounted by the current; the eddy was also very considerable, and the currents which resulted from it diverged almost as much as in the first experiment; the fall was very strong and very wide, and of the three separate currents which were formed on each side, those which joined the pier were the least elevated; they were all confounded together at some considerable distance.

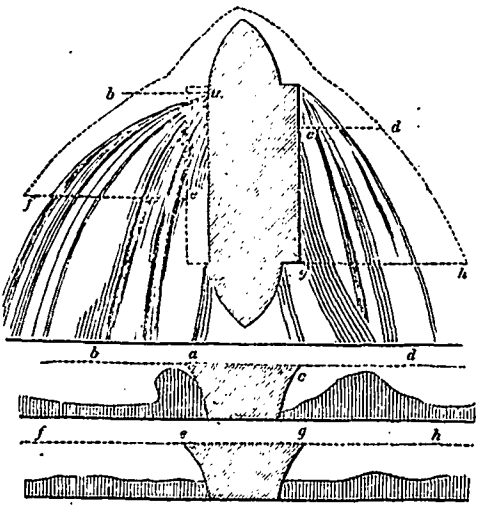


Fig. 2759.

We see by these experiments that whenever the faces of the starling are united to those of the pier by a curve which is tangent to them, and that the water does not surmount the springing of the arches, the fall is not formed at the shoulder, but two other currents are produced by the side of those which envelope the pier, which are not very rapid. The undermining then is not much to be feared in this case, the less so as the most rapid currents are those which are most removed from the pier: we may also remark that the elliptical form has great advantages over all the others, and occasions contraction much less considerable, because the lateral currents diverge at much less distances.

With regard to starlings the plan of which is triangular, the equilateral triangle is much to be preferred to the rectangular, which presents an obstacle almost as great as the rectangular pier, and is perhaps still more dangerous, the greatest fall taking place at the angle of the shoulder, whilst in the rectangular pier it is a little removed from it; if right faces are used, the equilateral triangle must be preferred, with the precaution of rounding the angle opposed to the current, if there be any fear for its solidity: the most preferable of all is the equilateral triangle mixtilinear; it unites the advantages of producing the least contraction and the least undermining possible, with that of presenting sufficient solidity to the projecting angle, since this angle is measured by the third of its circumference; the oval pier is the only one which occasions a less considerable contraction, and which may be preferred on this account.

The above experiments were made on a current where the rapidity was 3 metres 9 centimetres per second: as rivers have still greater in their overflows, two other experiments with a velocity of 4 metres 87 centimetres were made.

In the first (fig. 2760.) the base of the starling was formed by two arcs equal to the sixth of the circumference. The eddy produced at the meeting of the pier rose to a height nearly twice as great as that which had taken place for the rapidity of 3 metres 9 centimetres, and although there was no fall, the inclination formed along the faces of the piers was much more rapid: it did not, however, extend beyond the extremity of the square body, as may be judged by the profile *eagf*; this singular effect, which is observed in all similar circumstances, arises from the water being forced to flow, first with a considerable inclination, in virtue of which it can attain a velocity relative to the diminution of the section which the body of the pier causes it to experience, and when, on arriving below the bridge, the section widens, the velocity becomes what it was, and the water remounts almost to the level it had at first, so that for each point the inclination of the fluid has precisely the value which agrees with the corresponding velocity.

This experiment agrees with an observation made at the Bridge de la Drome by M. Montluisant, engineer of the Ponts et Chaussées. He marked the trace left by the waters on the surface of the piers on the starlings on each side after a flood, and found that the water, which had risen to nearly the same height on both starlings, was lowered about 1 metre 5 centimetres, at the angle of the shoulder of the one against the stream, and along the square

body; this effect is analogous to that just described, and, though it may appear extraordinary, necessarily takes place in all cases, but it is only evident where the rapidity is great.

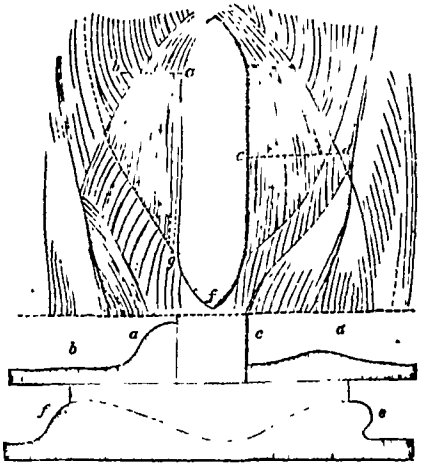


Fig. 2760.

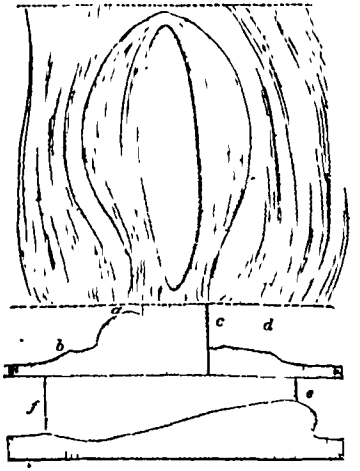


Fig. 2761.

The second experiment made with a velocity of 4 metres 87 centimetres per second, on a pier of an elliptical base. Fig. 2761. presented the same effects as that where the current had a velocity of 3 metres 9 centimetres, but they were more marked: hence we may conclude that the elliptical piers have the property of occasioning the least contraction.

The following table contains the principal dimensions of the currents observed in the preceding experiments.

	Form of the Base of the Starlings.	Height of the Water.		Distance of the Side Current.	
		Starlings.	Middle of the Pier.	Opposite the Angle of the Shoulder.	Opposite the Middle of the Pier.
	Rapidity 3·9 Metres per Second.	Metres.	Metres.	Metres.	Metres.
1.	Rectangle	0·041	0·018	0·099	0·203
2.	Triangle rectangle	0·036	0·014	0·081	0·126
3.	—— equilateral	0·034	0·016	0·036	0·072
4.	Half circle	0·038	0·023	0·023	0·095
5.	Triangle mixtilinear	0·036	0·016	0·027	0·077
6.	Ellipsis	0·032	0·011	0·018	0·061
7.	Triangle mixtilinear concave	0·036	0·009	0·036	0·104
8.	——	0·045	0·009	0·041	0·189
	4·87 Metres per Second.				
1.	Triangle mixtilinear	0·072	0·032	0·090	0·131
2.	Ellipse	0·059	0·045	0·045	0·081

These experiments and observations will enable us to appreciate the advantages and inconveniences of the different kinds of starlings, with relation to the size of the contraction which they cause the current to undergo; but we must not forget that the starlings are also useful in breaking the ice, and preventing any floating mass from stopping against the piers of a bridge, and diminishing the section, which would necessarily tend to produce an undermining.

Ice in places where the temperature is the same is more dangerous, as the course of the river is slower; in this case the rivers freeze more quickly, and the ice, which has time to acquire a considerable thickness, detaches itself in larger masses; it is essential then, in such cases, to take precautions in relation to the effect they may produce, and to make the projecting angle of the starlings more acute; if any fears are entertained for its solidity, it may be protected by bands of iron, or with a bar of iron placed in the masonry.

One of the best methods proposed for remedying the inconveniences resulting from ice in rivers is that which Perronet had adopted for the bridge projected over the Neva at St. Petersburgh; it consists in inclining forward the projecting edge of the starling; by

means of this arrangement the masses of ice which strike the pier tend to mount a little along this edge; their weight then acts on each side so as to break them, when each part is easily carried away by the current.

The form of the starlings down stream is not so important as those above: there are even a great number of ancient bridges in which they are omitted; in this case the space which they would have occupied is filled by stagnant water or a whirlpool, which it is necessary to prevent: it is therefore more advantageous to place them on both sides. When a river has been narrowed by an obstacle, such as a pier, the effect of which is to diminish the width of its bed, the two currents formed along its faces unite, describing a species of curvilinear triangle, and are then prolonged on each side the faces of the starling below bridge; hence result underminings, which are scarcely less frequent below than above; this should induce builders never to omit the starlings below bridge, but even to give them greater length than is customary. When the waters rise much above the springing of the arches, the form of the starlings has little influence on the nature of the contraction, which then depends principally on that of the arch, and the manner in which the intrados of the vault is united with the face of the starlings: one of the best methods of diminishing the contraction in this case is that adopted at the bridge of Neuilly: to effect it, the two faces of the starlings may be terminated by a curved surface agreeing with that of the vault; examples may be found at the bridge of Gignac, and at that of Navilly on the Doubs. In a design projected by Gauthey for a bridge at Auxonne, the starlings had the form of the prow of a vessel; when they are destined to divide the waters and break the ice, they should rise to the height of the greatest floods, or at least to that where the breaking-up of the ice takes place. We must observe that in semicircular arches the starlings diminish the contraction but little when the waters rise much above the springing, because the tympanum of the arch then presents a great surface, which is directly opposed to the current; and the starlings serve only to receive the first shock of the ice. In the last century much attention was paid to their decoration, which is not so important as the solidity of their construction: the crowning easily decomposes, and plants grow in the joints, which increase this effect, which might be prevented by forming them with great stones.

In *fig.* 2762. is the elevation and plan of one of the piers of the bridge of Moulins: both starlings above and below are triangular, with the angle projecting and rounded, which gives greater solidity, a precaution from whence no inconvenience can result, and which it is proper always to take; it is preferable to the use of a bar of iron in the masonry, which latter method should not be resorted to unless the bad quality of the stone obliges its use: the crowning has the form of a triangular pyramid; in the stones of which it is constructed, a vertical part has been preserved, which should have from 8 to 10 centimetres in height: starlings of a triangular base have sometimes been crowned with a cap formed by the prolonging of their faces cut by an inclined plane coming forward, as in the Pont au Change at Paris, fig. 2763.

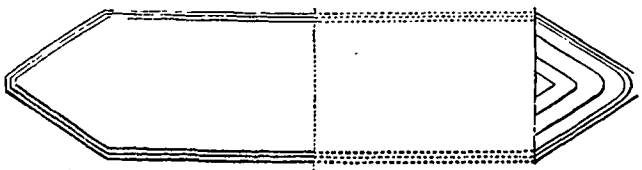


Fig. 2762. PIER OF MOULINS' BRIDGE.

Fig. 2763. PONT AU CHANGE.

Figs. 2764. and 2765. represent one of the piers of the bridge at Orleans. The base of the starling is terminated by two arcs equal to the sixth of the circumference; that of down stream is a half circle; the projecting angle of the upper starling is not sufficiently acute to require any rounding, and the form of the pier is that perhaps which best answers all the conditions required. The crowning of both the terminations of the starlings has a height which might be diminished; they are formed by a conical surface.

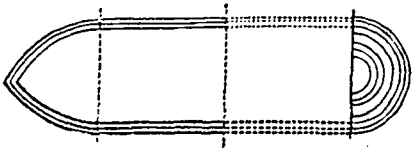


Fig. 2764. PIER OF ORLEANS' BRIDGE.

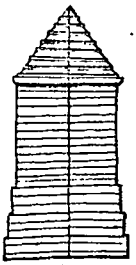


Fig. 2765.

Figs. 2766. and 2767. represent one of the piers of the bridge of St. Maxence: in some foreign works are examples of piers divided into two parts, the interval of which is covered

by a vault; these piers are very massive, and the bridge referred to is the only one in which it has been attempted to carry arches on so feeble and isolated points of support: but this construction has no particular utility, since it diminishes the expense but little: the crowning of the starlings is

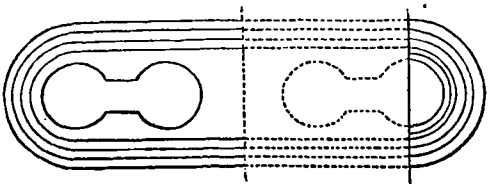


Fig. 2766. PIER OF BRIDGE OF ST. MAXENCE.

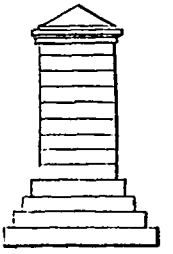


Fig. 2767.

formed by a conical surface of moderate height, and the pier being thin is constructed of a single stone.

Figs. 2768. and 2769. represent one of the piers of the bridge of Louis XVI., at Paris; the starling is formed by a column set in the square body of the pier, about ⅓ of its diameter, and surmounted by a capital, above which is placed a short architrave, over which

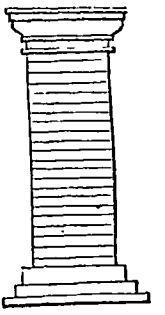


Fig. 2769.

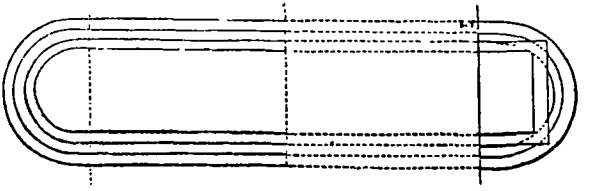


Fig. 2768. PIER OF BRIDGE OF LOUIS XVI.

runs a cornice with which the whole of the bridge is crowned, and which carries a square socle.

Figs. 2770. and 2771. represent a pier of the bridge of Neuilly; the plan of both ends of the starlings is a half oval, which commences under the vault itself, at the inferior origin of the corne de vaches; the crowning is terminated by a conical surface of little height. Sometimes the starlings of piers have been raised to the level of the upper parts of the bridge, making them carry columns, obelisks, figures, or even small shops, as in the Pont Neuf, at Paris: sometimes also the starlings form a space surrounded by a parapet, which towers above the bridge, serving as a shelter for passengers, and is serviceable when bridges are used as a promenade.

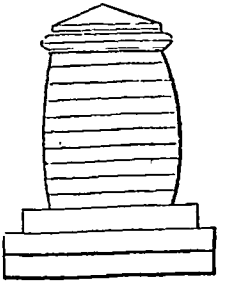


Fig. 2770.

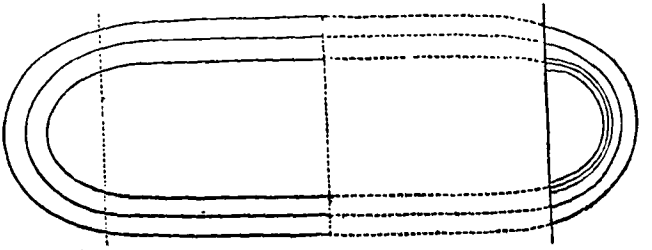


Fig. 2771. PIER OF NEUILLY BRIDGE.

That portion of the pier that carries the arch always preserves its oblong form, with its sides right lined and parallel; and under low water, this is increased in breadth downwards to the foundation, at the rate of from 1 to 9 inches for every foot in height, and the platform extending from 2 to 6 inches beyond the masonry; the rate of this increase of breadth must be governed by the nature of the bed of the river. At Neuilly, the thickness of the piers being at the springing of the arches only one-ninth of the span, it was necessary to spread the base very considerably.

Figs. 2772. and 2773. represent a pier of the bridge of Toledo, at Madrid, which is in this latter style; the base of the starlings is a semicircle.

Fig. 2772.

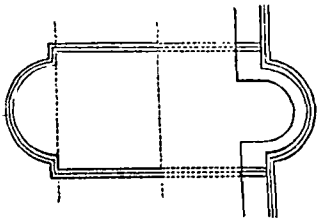


Fig. 2773. BRIDGE OF TOLEDO.

Quay Walls of Bridges. — In general, when the bed of the river is permanent and not liable to change, a wall A B is built on each side; the part B C unites the breadth of the bridge with that of the roadway, which is usually more considerable: the parapet of the bridge should be continued round this part. A C supports the earth at the abutments; the

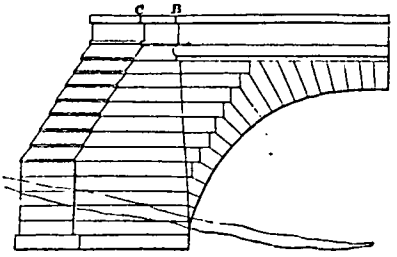


Fig. 2774. ABUTMENTS.

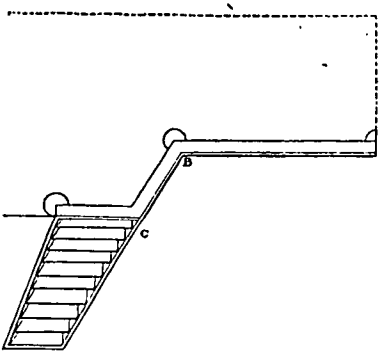


Fig. 2775. PLAN.

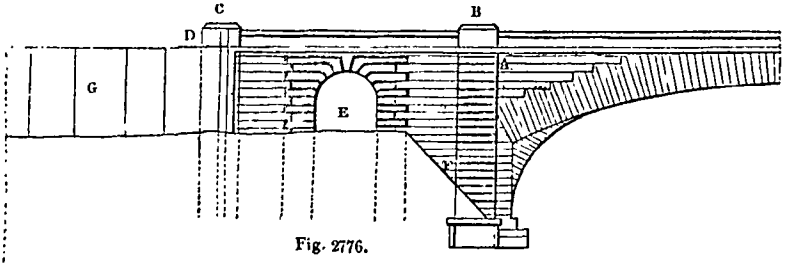


Fig. 2776.

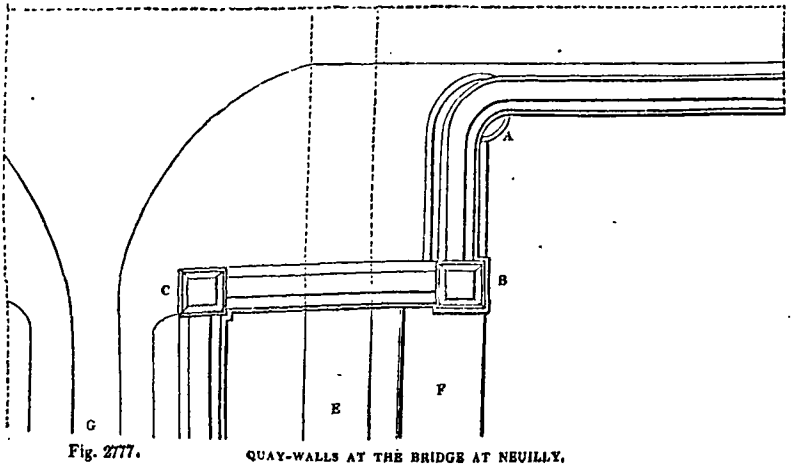


Fig. 2777. QUAY-WALLS AT THE BRIDGE AT NEUILLY.

upper portion of the wall is terminated by the talus of the slope, which is generally faced with masonry for some distance: its lower extremity is cut vertically at A, that it may have the requisite solidity at this part.

Fig. 2778. shows the wing-walls, as set out perpendicularly to the axis of the bridge. This arrangement does not allow so free a passage for floods, and ought only to be adopted when the natural banks of the river are not subject to injury from the running of the water.

When the river flows through a soil easy to be washed away, it is necessary to confine the bed where the bridge is situated. To do this we must construct embankments at the quays paved with stone, and continue them to such a distance above and below the bridge as may be necessary: the quays of several bridges, as that at Moulins, on the Allier,

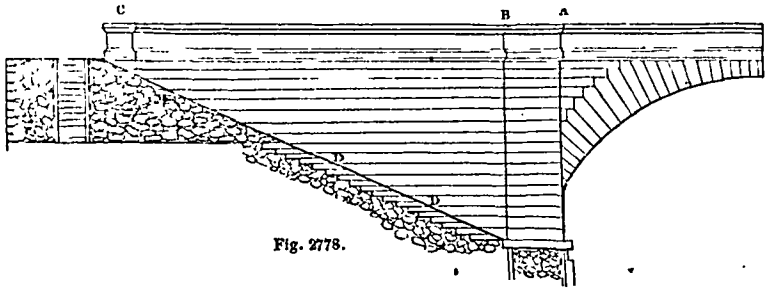


Fig. 2778.

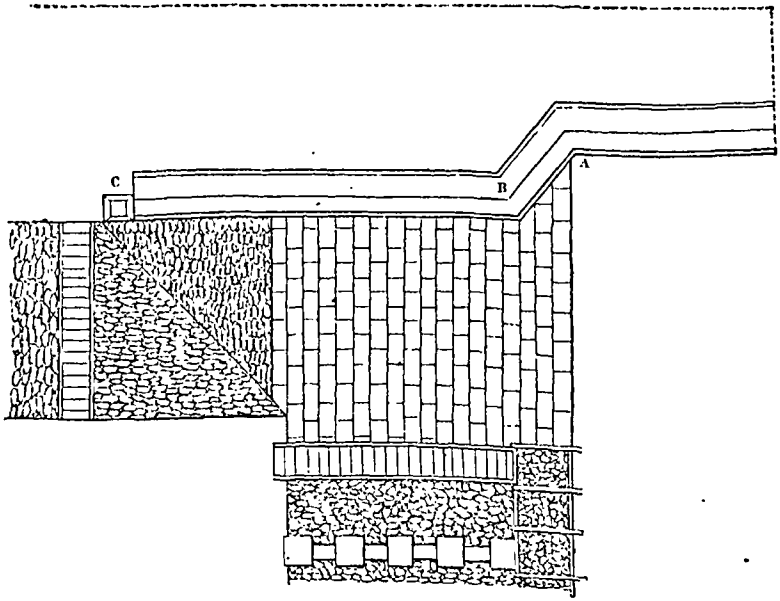


Fig. 2779. BRIDGE AT MOULINS.

are so arranged: A B is a splay joining the bridge with the road, B C is a return wall parallel to the axis of the bridge, D, D show the paved slope at the abutments, the toe of which is strengthened by two rows of piles, between which rubble-work is laid.

In cities, bridges are usually accompanied with quay-walls; the angle formed by their intersection with the bridge obstructs the passage of carriages, and is generally cut off by a straight or curved line, as at A; the angle formed by the quay-wall A B and the bridge is curved, and the projection occasioned by such an arrangement supported by a gathering over of the masonry.

At the bridge of Neuilly, the portion of the quay-wall A B unites the width of the bridge with that of the road, and the return wall B C is in the line with the edge of the footway, the interval between the two pedestals C and D answering to its width, and the quay-walls C, D are prolonged to a considerable distance, sustaining the road G G. To allow the passage for the towing-horses a tunnel and a road E E is constructed beyond the abutment.

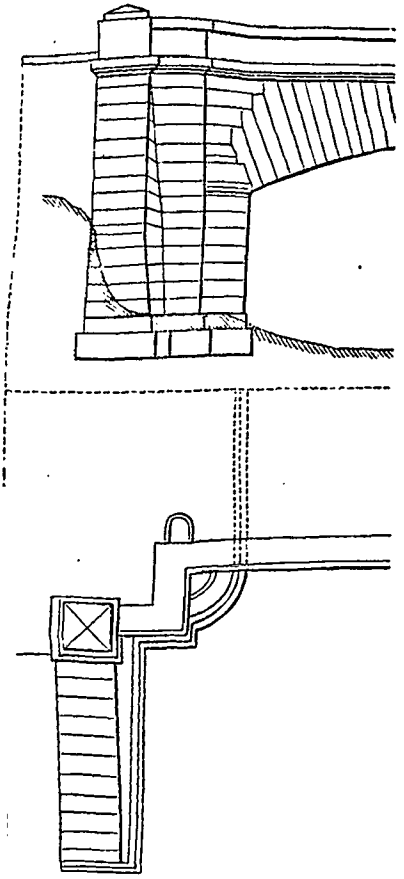


Fig. 2780. QUAY-WALLS AND PLAN.

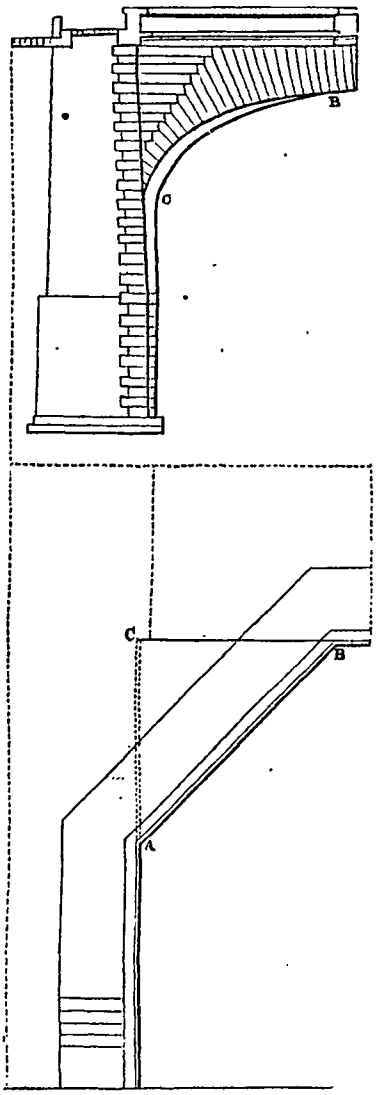


Fig. 2781. QUAY-WALL AT THE TUILLERIES.

When the width of the quay and breadth of he bridge is small, and the passage over much ised, the quay-walls must be set out, as at the ridge of the Tuilleries at Paris, where by means f a gathering over of the courses at A, B, C a play is formed, uniting the bridge with the oadway, at the middle of the first arch; at he Pont au Change in the same city this splay extended still farther, but it is supported ifferently.

Foundations. — The establishment of proper foundations for a bridge, where the points f support carry all the weight, is of the greatest importance: rock is almost the only unexceptionable foundation for hydraulic constructions, and even in that case it is necessary to ascertain whether the thickness is sufficient to be entrusted with the weight intended to be put upon it.

A soil composed of clay and gravel often forms a very compact bed, upon which the masonry may be placed without pilings; but sand, peat, and compressible earths require piles to render them sufficiently compact and solid. In deep rivers piles have been driven over their entire beds, so that their heads stood level with the low water, and the spaces between filled with loose stones; but this method, though formerly much practised, has been long discontinued.

Cofferdams are now generally made use of for laying in the foundations of the piers and abutments of a bridge, constructed to suit the particular position of their locality: they are commenced by driving two rows of vertical and plank piles, between which

a mass of clay is thrown, or by driving main piles and laying strong planking across them in a horizontal position, or by driving one row of gauging piles, and filling the spaces between with pile planks driven vertically: at page 445. is a description of one of the largest cofferdams required; it is therefore unnecessary to enlarge upon it, or to mention others, the one referred to having performed its duties admirably.

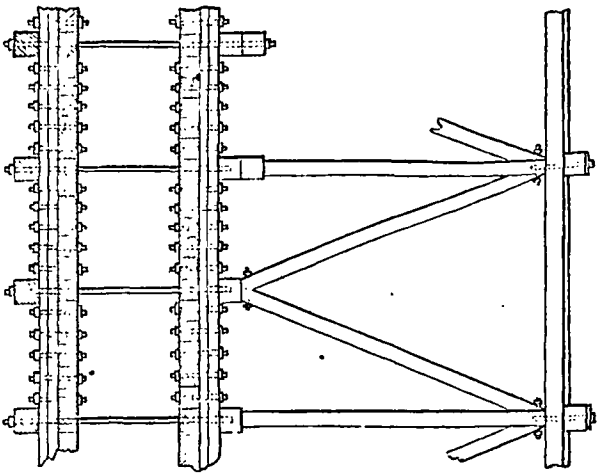


Fig. 2782. COFFERDAM.

Sounding the Soil to ascertain its nature is the next work, which is done by an iron rod driven in by the pile-engine, or by an auger that will bring up the soil, as in sinking an artesian well. Soundings have been taken to the depth of 80 feet by using a strong chest made of planks, about 18 inches square, the bottom of which was shod with iron, that it might more easily force its way through the soil: and M. Fauvelle, of Perpignan, has described an easy method of boring to any depth, either for the examination of the soil or for obtaining water. He observes, "if through a hollow boring-rod water be sent down into the bore-hole as it is sunk, the water in coming up again must bring with it all the drilled particles:" he had therefore an apparatus made composed of a hollow boring-rod of wrought-iron tubes screwed end to end, the lower end being furnished with a perforating tool suited to the strata in which it had to work; the diameter of the tool was larger than that of the tubular rod, in order to form an annular space around it, through which the water and the excavated material might rise up. The upper end of the hollow rod was connected with a force-pump by jointed or flexible tubes, which followed the descending movement of the boring-tube for an extent of some yards; this tube may be worked in the ordinary way, with a turning handle or a jumper: the pump must be first put in motion; a column of water is sent down to the bottom of the bore-holes through the interior of the tube, which, rising in the annular space between the exterior of the hollow rod and the sides of the bore-hole, creates an ascending current, which carries up the triturated soil; the boring-tube is then worked like an ordinary boring-rod, and as the matter is acted upon by the tool at the lower end, it is immediately carried up to the top of the bore-hole by the ascending current of water: the usual necessity of drawing up the boring tube to clear it is therefore avoided, and a great portion of time is economised. A bore of 6 inches in diameter has been made to the depth of 560 feet in 140 hours at Perpignan, and this system is now universally adopted in France.

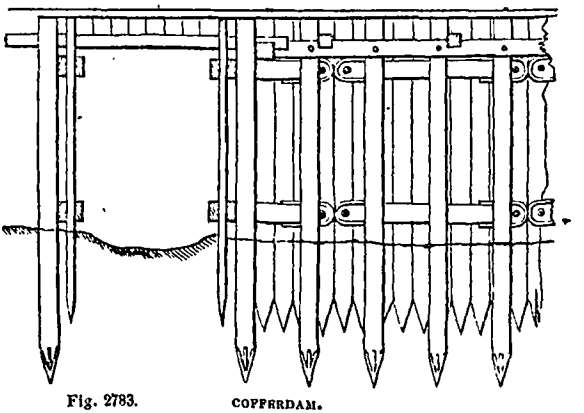


Fig. 2783. COFFERDAM.

Cofferdam for building the River Wall of the new Houses of Parliament. — The excavations for the works were commenced on the 1st of January, 1839. The mud on the shore varied in thickness, and beneath was a bed of gravel 14 feet in depth; under this was a stratum of stiff clay, into which the piles were driven 2 feet, a trench being first dredged in the line

of the dam, 8 feet in depth and 27 feet wide; the piles were of Memel timber, 12 inches square and 36 feet in length; these were all driven till their tops stood 4 feet 6 inches above Trinity high-water mark of ordinary spring tides; to these were attached the waling-pieces; and the outer sheet piles, formed of whole timber 13 inches square, and of similar length to the others, sawn perfectly square, were driven close together and firmly bolted to the waling-pieces. The inner sheet piles were of half timber, of the same length, and driven to the same depth: between these rows of piles, the space above them was occupied with horizontal pieces, bedded down to them, and made fast with bolts to furring pieces, inserted above the waling of each gauge pile. Throughout the whole length of 920 feet the dam was secured by dingonal braces, extending back to the old river wall, against which they had an abutment: the outer and inner rows of piles were held together by three rows of 2½ inch wrought-iron bolts: when all the piles were driven, the whole space between was cleared down to the clay, and then filled up with stiff clay, mixed with a small quantity of gravel.

The foundations of the river wall were got out in lengths of 50 feet, and the footings laid on a bed of concrete varying in thickness from 1 to 6 feet; this was composed of six parts of gravel and sand to one of ground lime, made from the lower stratum of the chalk formation. Along the face of the wall was a row of elm sheet piles, 8 inches in thickness, and from 10 feet to 12 feet in length; after being driven close to each other they were spiked to an oak waling-piece, and further secured by inch wrought-iron bolts at every 4 feet distance, which passed 6 feet into the wall, where they were held by cast-iron washers bedded between the courses.

The two lower courses of the wall were formed of York landings, 11 feet in width, and 6 inches in thickness; on these were laid two courses, 15 inches thick, of Bramley fall-stone, and above the stone facing of the wall, Aberdeen or Cornish granite was laid in courses varying in thickness from 26 inches to 19 inches at top; the front had a curve of 100 feet radius, and the whole filled in at the back with brickwork; the total thickness at bottom was 7 feet 6 inches, and at top 5 feet; at every 20 feet was a counterfort, 3 feet 9 inches in width, projecting 3 feet 4½ inches; the height above the footing is 25 feet 6 inches.

The face of the foundation of the main building is 28 feet 9 inches behind this river wall, and the space between the two was entirely filled up with concrete, formed of ten parts of gravel and one of ground lime: the cost of the excavation, cofferdam, and river wall was 74,373*l.*

Excavations are usually performed by a class of men called navigators, who also level down the bed to receive the foundation: to assist the labour of wheeling out the soil, it is

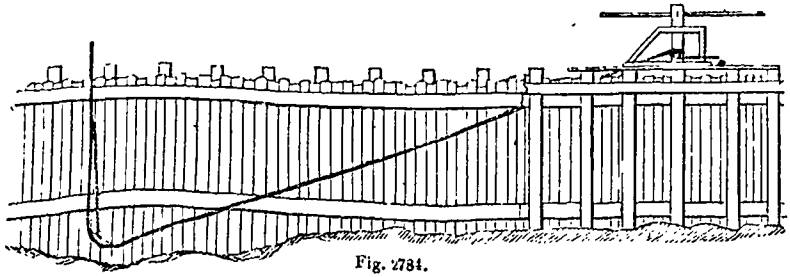


Fig. 2784.

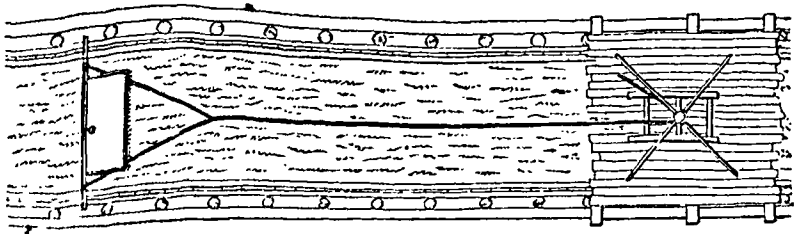


Fig. 2785. DRAG EMPLOYED AT ORLEANS BRIDGE.

often necessary to lay down temporary bridges, and to construct different heights of scaffolding; the method of loading and unloading the boats employed for this purpose has already been described.

Dragging is generally resorted to for removing the soil which lies below the level of the water, which is done with an iron shovel or scoop with a long flexible handle, or with the dredging-machine. The drag used at the bridge of Orleans was moved by a windlass, and could be lifted at pleasure.

Of the Construction of the Piers and Abutments.—The material of which these are formed is granite or hard stone cut into headers and stretchers, the length, breadth, and depth varying according to circumstances; excess of length should be avoided in either, which would render them liable to fracture. Each course of stone around the outside should be laid header and stretcher alternately; the latter should be from 18 inches to 2 feet in breadth, and the header should occupy one-third of the whole face, and be 3 feet or 4 feet in length; their upright joints should be perfectly square, at least 1 foot in from the face, and in no part more than 1 inch in width. The interior or filling-in stones should be of equal height to those on the outside, their upright joints not more than 1 inch in width, and they should break joint at least 12 inches; the bed and upright joints of all the courses should be flushed in with proper mortar, as they are laid, and the outer joint, when compressed, not show more than $\frac{1}{8}$ of an inch: the whole should be run with grout. In many places it was formerly the custom to fill in the interior of the piers with rubble-work, a practice that cannot be too much reprobated, as such constructions can never be depended on.

Raising the Centres is the next operation after the abutments and piers are terminated, and is usually performed from a scaffold or temporary wooden bridge, constructed for the purpose. The centres rest on wedges placed upon the bearing timbers, by which they can be eased at any time; the wedges are in separate pairs, crossing each other under each frame, or are fixed upon a piece of timber, extending across the whole width of the soffite of the intended arch, and passing between all the centre frames and the supporting frames or beams; the wedges are sometimes formed or fixed upon the timber, which is placed longitudinally under the foot of each rib of the centre, resting on the supporting frame: when it is requisite to ease the centre, either the wedges or the timbers on which they are fixed are driven along each other, by which the wedges are made to take up a new position, and the centre descends very gradually. Beams mounted like a battering-ram are used to effect this purpose.

The Construction of the Arches is commenced after the centres are fixed, and the masonry of the piers and abutments is carefully adjusted. When the voussoirs begin to bear upon the centres, the latter are liable to a partial change of form, which must be provided for by loading them in various parts as the works proceed. Great care should be taken to make each course of arch-stones point in the direction of the radius, and to do this effectually their thickness should be marked upon the outer ribs, and their line of direction upon the lower part of the beams: the courses should be laid equally on each side of the centre, an excess of weight on either side being likely to produce an alteration in the form, and the top must be loaded until the arch is complete: the key-stone should occupy its proper place, but not be driven home until the whole is finished; all the back and end joints of the entire arch are then wedged up with slate, run with mortar, and left some time to dry. The masonry of the spandrills are brought up to about one quarter of the height of the arch, after which the centre may be removed. The soffites of the arch and all its joints are then pared, cleaned, and pointed with mortar; for this purpose Perronet contrived a hanging scaffold at the bridge of Orleans, which could

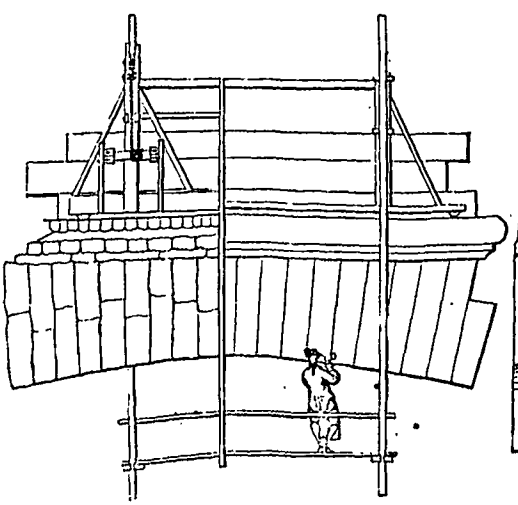


Fig. 2786.

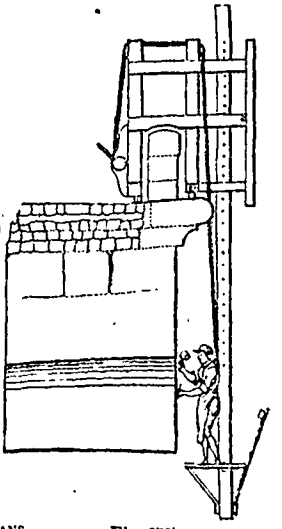


Fig. 2787.

SCAFFOLD FOR THE BRIDGE OF ORLEANS.

be made to roll along the parapet, and by means of a windlass be raised or lowered as required.

The Spandrills and Wing-walls should progress as soon as the centres are struck, and we cannot do better than refer to the construction of London Bridge for the manner in which they are to be carried up.

CHAP. XXVI.

ON THE CONSTRUCTION OF FASCINES AND BASKET-WORK FOR JETTIES. —RIVER, SEA, AND DOCK WALLS.

In many parts of Italy *gabions* made of twigs and branches, in the manner of basket-work, are filled with stones laid one on the other, to form rivers and sea walls: this method is both expeditious and convenient, and when laid down and covered with sand or mud, it is several years before the basket-work is destroyed, and the stones become consolidated and require little further adjustment: such osier-work may be made where it is to be used. and as the manufacture advances, the baskets can be filled with stones or other hard material.

The cylindrical form gathered in at the top is given by placing eight upright rods on the ground, with a hoop to hold them in at the top; the osiers are then woven in alternately up to the hoop; the eight rods are then united at the summit, and the whole finished to the required form.

There are several varieties of this work, which is admirably adapted to the purpose for which it is employed; sometimes a breach in a river wall is stopped by laying in several rows of these gabions, which serve the purpose of sand-bags. When shell-fish, muscles, &c. attach themselves to works of this kind, they should not be removed, as they contribute very much to their consolidation; to protect banks so formed from injury from boats, fender piles are driven in at convenient distances.

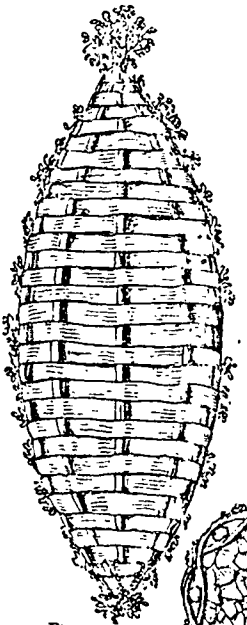


Fig. 2788.

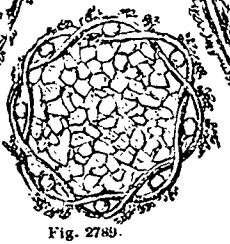


Fig. 2789.

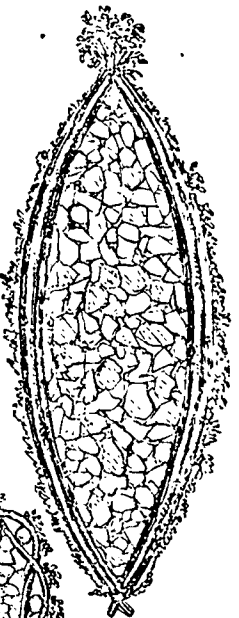


Fig. 2790.

Rods 15 or 16 feet in length, interlaced round the heads of several piles driven either in rows or around a circle, form a very efficient barrier to ordinary streams, and when several rows are repeated, filled in with chalk or stones, will last a considerable time: such was the practice on the banks of the Thames, but the wash now produced by the steam-boats has occasioned this practice to be abandoned, and a more efficient one to be introduced, which consists of dressing the slope of the banks and laying on them a pavement of heavy stone.

Wherever sand is deposited by the waters on a coast, and it is desirable to retain it for the purpose of forming a sea-wall: that which is furthest distant from low water is first secured by small bands of osier or basket-work; the winds not having any power to scatter it, in the course of a short time it becomes consolidated; should any clayey or earthy

matter be held in suspension, by allowing it to deposit itself over twigs of trees or fascines firmly pegged down, a considerable quantity will be obtained after filtration, and on the

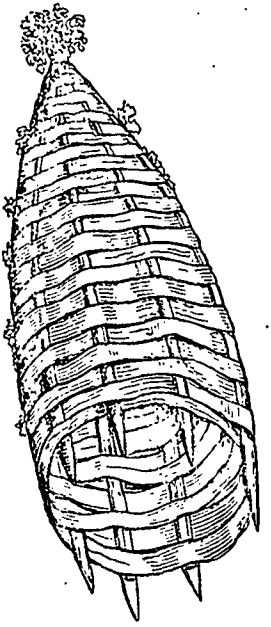


Fig. 2791.

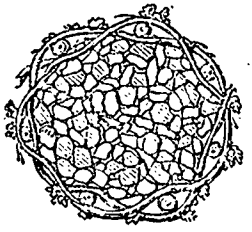


Fig. 2792.

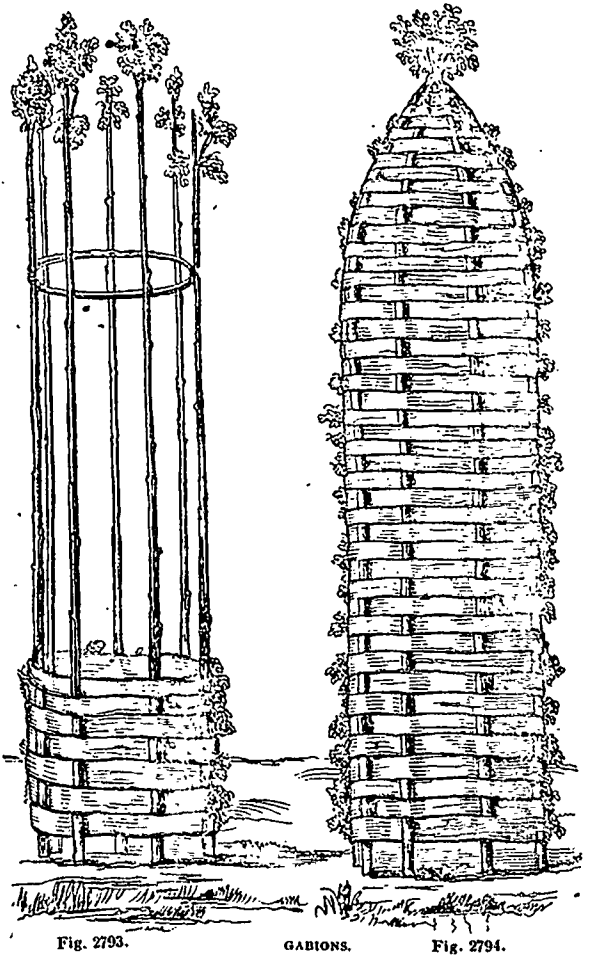


Fig. 2793. GABIONS. Fig. 2794.

whole becoming bound together, a fresh layer of fascines may be pegged down, upon which another course of earthy matter will be deposited, and the work advanced till a certain height

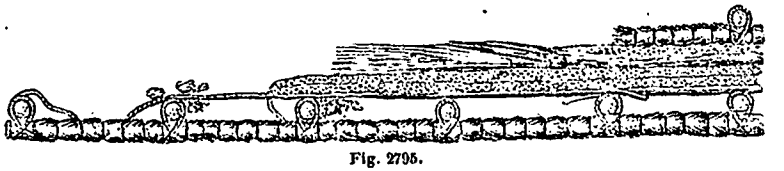


Fig. 2795.

is attained above the level of the salt water; after which, by exposure to the sun and air, the surface will be rendered fit for vegetation, producing first grass or rushes, which mixing with more earthy matter continue to rise above the water altogether, and at last become fit for agricultural purposes. By means of basket-work an island may be formed in shallow water, the mud being deposited within it at the time of high water; when the tide retires, the whole will settle, and the water draining off, become more and more consolidated at every fresh deposit, the wicker-work being admirably adapted to allow the surplus water to pass away, and the more solid matter to be retained. When such operations were conducted upon a large scale in Holland, the islands were at first of no very considerable

extent; these were by degrees united, until large tracts of very valuable land were obtained: Spanish broom and twigs of various trees, as the alder and willow, are well adapted for this purpose.

The general plan in Tuscany for forming sea or river walls is to lay down a framework for round timbers, which being well secured, bundles of faggots or branches of trees in one direction are laid upon them, and another layer or several in a contrary direction; this is repeated several times, and where the water deposits any earthy matter, it is effectually retained.

An earth bank covered with fascines formed in this manner is generally sufficiently protected, and will continue sound for several years.

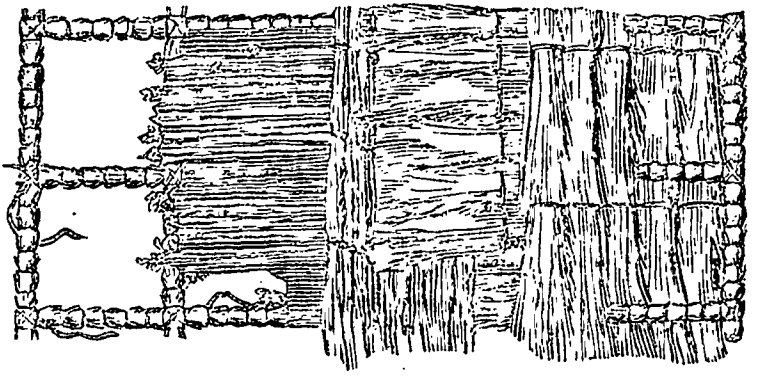


Fig. 2796.

Jetties at the entrance of small harbours are frequently for the sake of economy formed with fascines, and the same kind of work is sometimes adopted as a temporary expedient, to facilitate the construction of others more solid: the height to be given to jetties of this description should be always proportionate to their extent of base, which generally is as 1 to 3; so that a jetty 24 feet in height, where the summit is to be left 5 or 6 feet in width, should be at least 78 feet in width at its base. In setting out the work due regard must be had to the increasing depth of the water and to the necessary spreading of the base.

To prevent the fascines from being displaced after they are laid, they may be covered

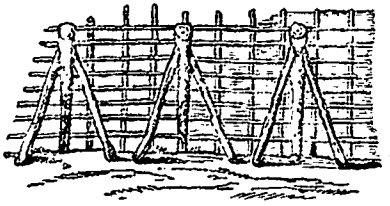


Fig. 2797.

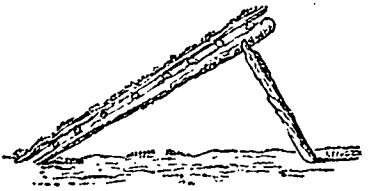


Fig. 2798.

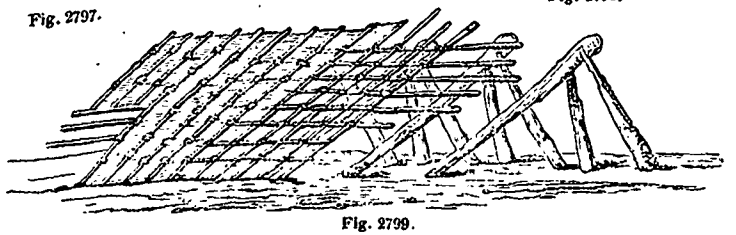


Fig. 2799.

with a framework of rough timber, over which rods, planks, or boarding may be nailed or tied down: timber 4 or 5 inches in diameter laid with the proper inclination, and secured to the heads of inclined piles driven for the purpose, may be covered with smaller timber laid in squares, and the interstices filled either with stone, chalk, or gravel; where there is a deposit from the water, land may be gained by allowing filtration through such embankments, taking care to retain the solid matter, for which purpose baskets closely woven are well adapted; the foot of such jetties should be well protected at the toe by a row of piles.

Triangular baskets filled with stones are sometimes laid in rivers subject to floods, to protect the starlings of the bridges.

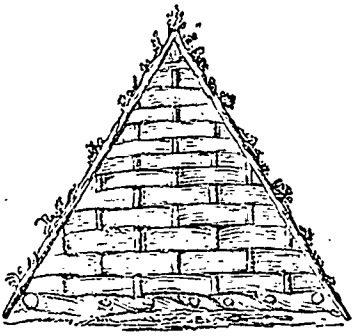


Fig. 2800.

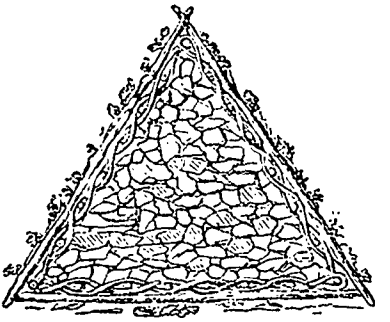


Fig. 2801.

Groins used on the coast for preventing encroachments of the sea are made of timber and constructed across a beach, between high and low water, perpendicular to its general line: they are for the purpose of retaining the shingle or accumulating more, and are formed of piles, planking, land ties, blocks, tail piles, keys, and screw bolts. Their length depends on the nature of the beach upon which they are to be formed; those on the Sussex coast vary from 150 to 250 feet, and have oak or beech piles from 12 to 25 feet long, shod with iron, their scantling being 8 inches by 6½. The planking is 2½ inches thick; the land ties are about 25 feet in length of rough timber, and the bars which secure them at the ends are 13 feet 6 inches in length, and 12 inches by 5; the land tie bar blocks are 2 feet in length, and the tail blocks 2 feet 6 inches, their scantling 6 by 3: the screw-bolts are of inch-round iron, 2 feet 9 inches long. Every 16 feet in length of these groins contains four piles, one land tie, with tail piles and keys, one land tie bar with two blocks 2 feet long, and two short bolts, 180 superficial feet of planking, and 140 6-inch spikes, the cost of which is about 30 pounds.

To accumulate more shingle, the first pile is driven at the high water mark of neap tides, leaving its top level with that of spring tides; the next is driven at the point on the sands, beyond the bottom of the shingle to which the groin extends, leaving about 4 feet out of the beach; the tops of these two piles formed the general slope of the groin, unless where the beach is curved, when it was slightly modified to meet the curvature.

From the high water mark of neap tides the piles are carried back nearly level to that of spring tides, or further if necessary, and driven 4 feet apart from centre to centre, so as to admit the planking to pass alternately between them; the land ties are placed about one-third from the top of the planking, and usually on one side, so as to resist the action of the most prevailing winds. The groins are placed from 50 to 100 feet apart, and are raised as the shingle mounts.

Of River and Sea Walls. — Before walls of masonry are commenced for this purpose, the soil must be carefully examined, and the foundations laid in at sufficient depths below the current or flowing in of the tide; the footings must also be protected by internal and external rows of planking and piling; another matter for consideration is the escape of the water from the land, which sometimes, if not properly drained off, will either wash away the soil on which the foundations are laid, or thrust the whole out of a perpendicular direction; and when river walls are built upon the heads of piles not properly secured, they will often press the latter out of the position in which they were driven, and destroy the strength of the work. Sea walls, from being exposed to a great force, must be so set out that the necessary resistance is obtained, and the slope next the ocean should always be as flat as possible, that the waves may break easily upon it: in those instances where a slope of 1 in 30 has been given, and the surface paved with stone,

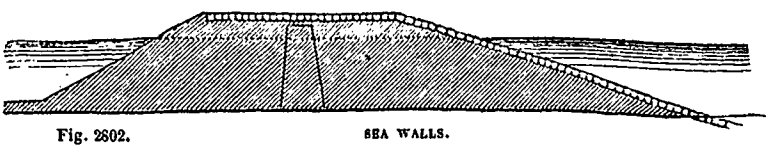


Fig. 2802. SEA WALLS.

there has been less expenditure to keep it in repair than in others made more steep. Dock walls require that the interior should be puddled with clay, as it is found that at low

water the pressure from the interior sometimes forces the water through the banks, unless this precaution is taken.

Walls constructed of earth to hold water in a reservoir or filter are set out in the same manner, but as the pressure to which they are subjected is only on one side, the inclination of their slopes is varied according to circumstances. Puddling a wall in the centre is always

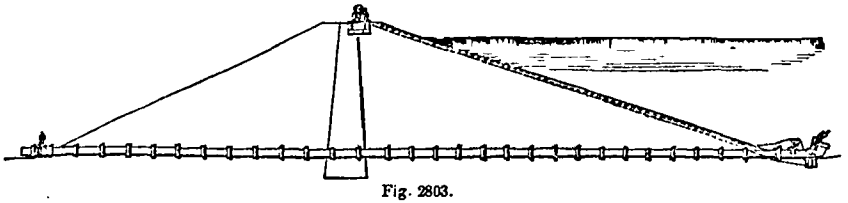


Fig. 2803.

advisable, and before the work is commenced, it is usual to lay in the main or pipe, through which the contents of the reservoir are to be admitted or discharged; if this main be required of considerable size, a brick tunnel may be substituted, which permits of attention to the hydraulic works, and gives facility for their repair.

Sea Wall at Brighton is constructed with sand and shingle taken from the beach, and cemented together by an hydraulic lime made in the vicinity; salt water was used at first, and answered the purpose well. The wall is at the top 2 feet 6 inches in thickness; the back is built perfectly perpendicular, and the front has a talus equal to one-third of the height; its base is on the chalk; its height varies from 40 to 70 feet. The lime was obtained at Bycombe, where chalk marl lies under the lower chalk formation, and is of the same quality as the Dorking and Halling limes; it is found generally in the north escarpment of the South Downs, and in the southern of the North Downs. After being properly burnt it was not ground but slaked at once, and at the same time mixed with three parts sand; it was then put into a pug-mill, and combined with three parts of shingle, wheeled away and thrown down upon the wall, into a case made of boards lodged together; the rear lodges were strutted against the face of the chalk, and the front was held to them by iron ties, which were afterwards drawn by taking out the pins, and again used as the work advanced. The whole was executed at a price equal to 3*s.* 4*d.* per cube yard.

The Humber Dock Wall is in perpendicular height 32 feet; at top it recedes 6 feet 8 inches from the perpendicular line; the thickness of the wall is 6 feet; the projection and

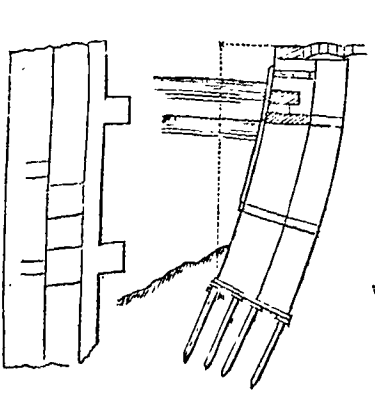


Fig. 2804. HUMBER DOCK WALL.

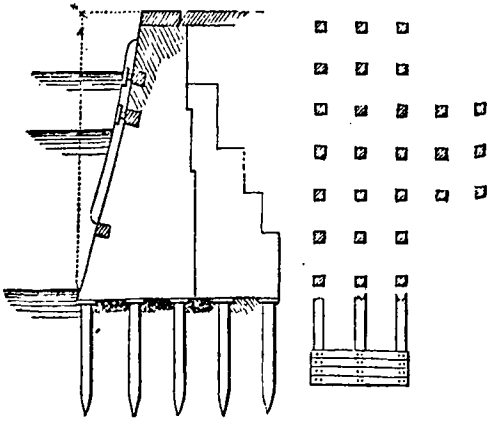


Fig. 2805. DOCK WALL.

width of the counterforts, which are 15 feet apart, is 3 feet 9 inches. Oak fenders 12 inches square are placed along the walls to protect them; these project 8 inches before the face; there are also two horizontal rows of fir fenders, 7 inches square, let into the uprights by short tenons with angle pieces, to prevent vessels catching underneath or riding upon them as the tide rises or falls.

The Humber Dock Wall has the foundations all piled, with a row of 6-inch grooved sheeting piles in front; those upon which the wall is founded are 9 inches square, and the counterforts 8 inches in diameter, all driven with a ringing engine, and a ram of 9 cwt. worked by fifteen men: longitudinal sleepers of half timber were bolted down upon

the heads of the bearing piles; the sheeting piles were spiked to an inner waling of the same size, and the whole was covered with 4-inch close planking, on which the walls, which were of brick, rested: their thickness at bottom is 10 feet, at top 4 feet 6 inches; the height is 24 feet 6 inches, and it batters 5 feet. The counterfort at the back is 9 feet thick, and projects at bottom 8 feet, and at top 3 feet 6 inches from the back face of the wall.

Retaining walls built of stone in some of our tidal harbours are 12 feet in thickness at the base and half that width at the top; in many instances the face is curved with a radius of 80 feet, to allow the nearer approach of the vessels to be loaded and unloaded: and the fenders of oak, which are placed perpendicularly, are secured by iron ties.

It is important to carry the foundations of all retaining walls to the depth of 6 or 7 feet below the bed of the harbour or basin where they are constructed, and to protect them at the toe by rows of piles; in many places the oak fenders are capped with iron, and lewis iron eye-bolts are introduced to secure vessels.

Where the soil of the foundations is soft, a timber platform is generally laid below the footings, the toe of which is protected by sheet-piling.

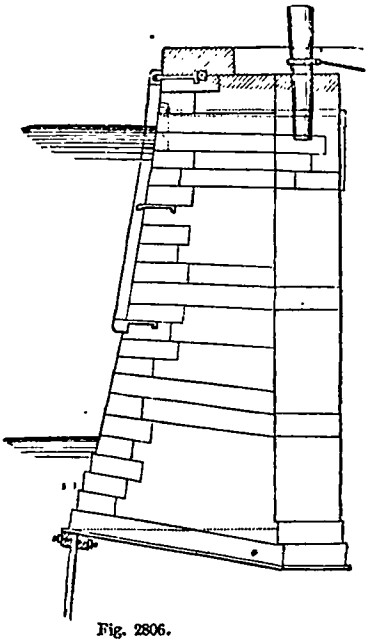


Fig. 2806.

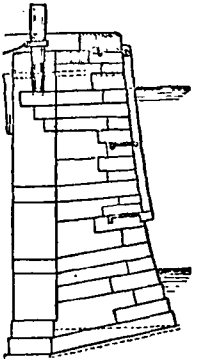


Fig. 2807.

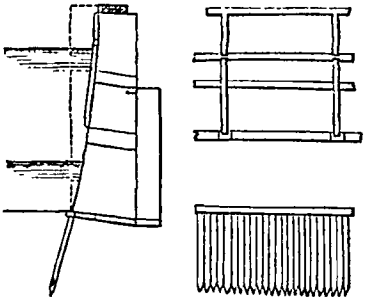


Fig. 2808.

The Brunswick Wharf at Blackwall, wholly of iron, was constructed in 1834. A trench 6 feet in depth was dug along the intended line, and the timber guide-piles afterwards driven: the iron piles, which are in two heights, with a socket-joint secured by a screw-bolt, were then driven at intervals of 7 feet, and the intermediate spaces filled in: each sheet-pile is secured at the top by two bolts to the uppermost wall of the woodwork behind; the iron

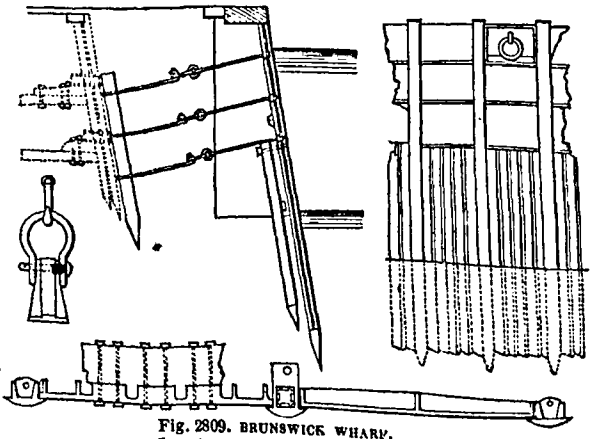


Fig. 2809. BRUNSWICK WHARF.

plates filling up the spaces over the sheet piling are bolted to the main piles and to each other, and the joints stopped with iron cement: the plates that receive the mooring rings are cast concave; the whole of the work is backed by a wall of concrete, and the coping is granite. The sheet-piles are 1¼ inch thick, and the weight of each pile 17 cwt. The length of the wharf is 720 feet, and the quantity of iron used was upwards of 900 tons: the height of the sheet-piling is 22 feet, and that of the plates above 14 feet: the average rise of the tide is about 18 feet.

Dykes of Timber filled in with Stone were formerly much adopted, and at many of our ports, as well as on the continent, we find them executed in oak: in some instances their form is curvilinear, to suit the bulge of the vessel that is to be secured to the quay; and by spreading out the base to obtain this, additional strength is acquired: the whole is braced horizontally by a succession of St. Andrew's crosses, and being afterwards filled in with stone and planked on both sides, is rendered tolerably secure.

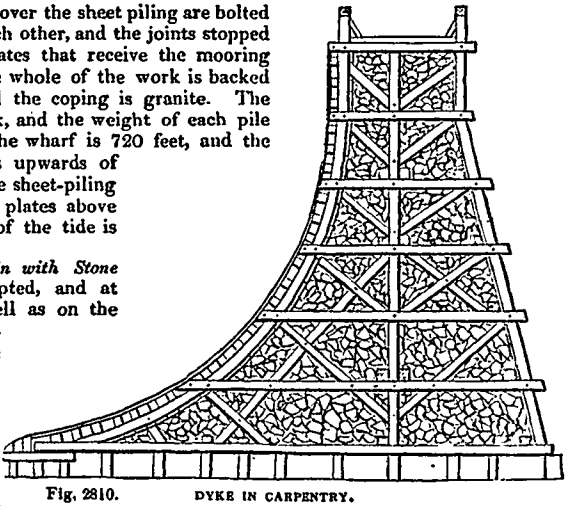


Fig. 2810. DYKE IN CARPENTRY.

At the Quay of Rouen the sides were made to incline gradually, and a filling in with courses of masonry contributed to its strength: but this mixture of timber with masonry is not durable; it frequently requires repair, and is only adopted where timber is abundant or of little cost.

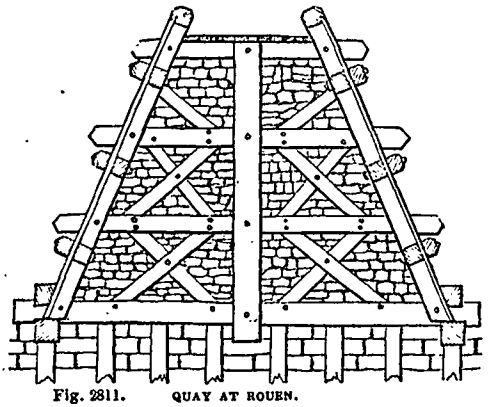


Fig. 2811. QUAY AT ROUEN.

In another variety of dyke the thickness is obtained by slanting one side only, or giving it a greater inclination than the other: the base is in width half as much more as the height, and strongly braced and tied together by horizontal timbers, laid throughout from one side to the other, and further strengthened by inclined struts, abutting against perpendicular timbers which pass entirely through its height.

The quays at Rouen are admirable pieces of construction, notwithstanding the objection just referred to: in some instances the walls rest on sleepers, filled in between with beton or rubble and mortar, guarded on the waterside by rows of sheet-piling secured to timbers laid in the wall; and where the ground was in a soft state, and could not be depended upon, piles of considerable length were driven and braced, as shown in the figure; they excited for years the admiration of engineers, and are allowed to be peculiarly well adapted for their situation.

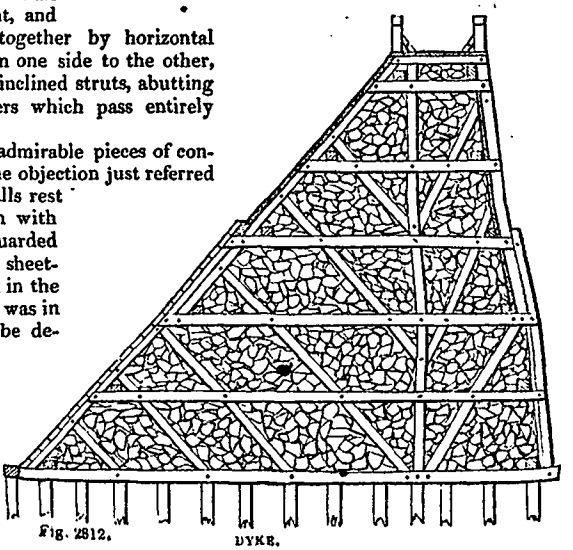


Fig. 2812. DYKE.

In facing the sides of a pier or dock wall with timber, series of land-ties are requisite to prevent the pressure outwards, as well as to act as struts against its action inwards: a strong capping of timber framed to the heads of the piles, a brace secured by iron straps, and a horizontal tie halved on to the sides and heads of the piles, may be so put together as to endure for a length of time, if secure from the ravages of the *teredo navalis*.

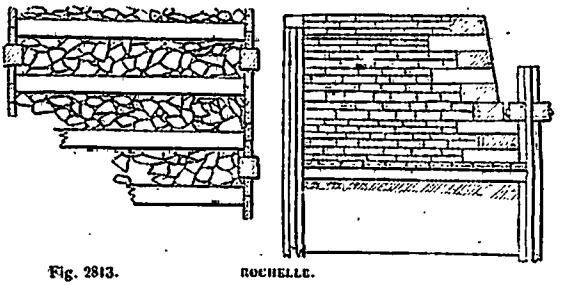


Fig. 2813. ROCHELLE.

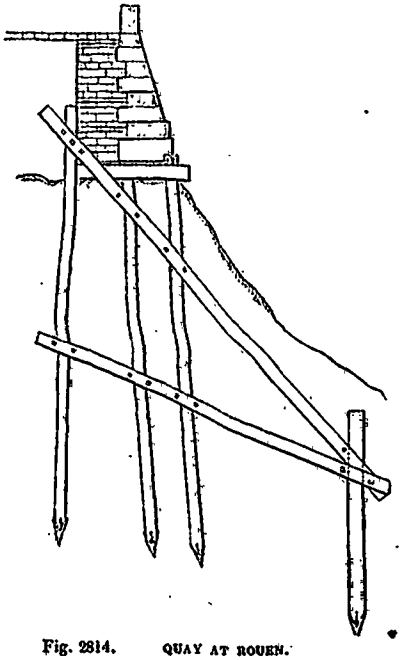


Fig. 2814. QUAY AT ROUEN.

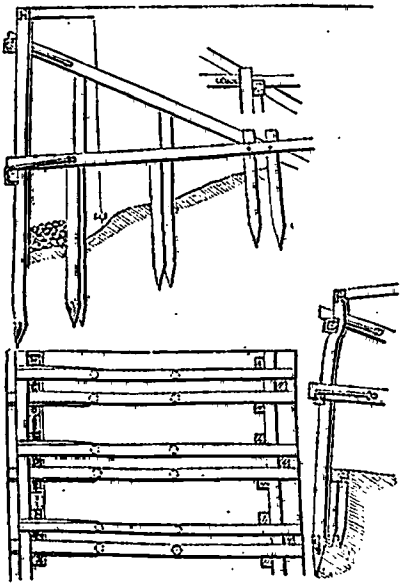


Fig. 2815

The Piers of the Humber Basin are 18 feet across their top; the main piles are 14 inches square; those of the outer wall of the same dimensions; those of the inner wall 12 inches by 6 inches; the cap sill 12 inches by 10 inches; the joists 7 inches by 4 inches; the ties 12 inches by 6 inches; sheet-pilling 6 inches thick, and the planking 3 inches.

In the construction of piers of this kind great attention should be paid, so that they have sufficient strength to resist the force which is often exerted during storms against them. Up to a certain height

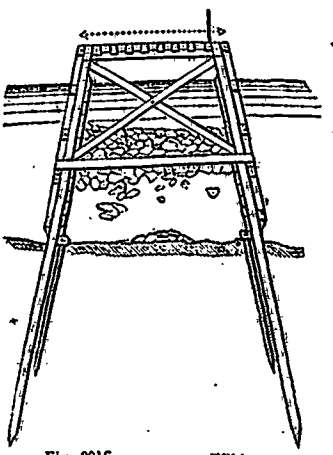


Fig. 2816. HULL.

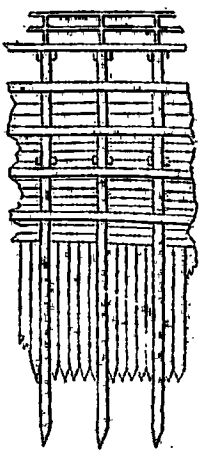


Fig. 2817.

they require to be loaded with stone, or filled in solid; and where this is done, planking and sheet-piling are required to keep the materials so deposited within the framework from washing away.

The foundations of walls constructed in the sea or in deep rivers require the greatest attention on the part of the engineer: where the soil is soft, and cannot be depended upon, it is necessary not only to pile it closely all over, but to lay on the heads of the piles a piece of whole timber, and then fill up level with rubble; another series of timbers of the same scantling should be laid in a transverse direction, and when brought level by another filling-in of rubble masonry, the wall is built upon it: such was the system adopted by Perronet when constructing the bridge at Neuilly.

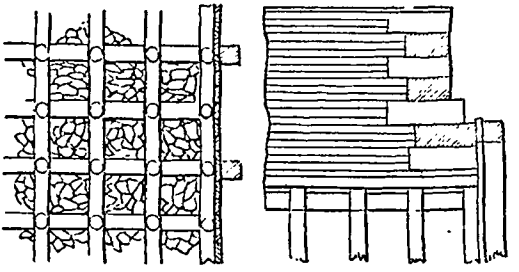


Fig. 2818. NEUILLY FOUNDATIONS.

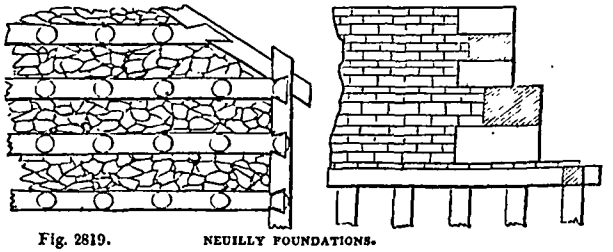


Fig. 2819. NEUILLY FOUNDATIONS.

At Rochelle similar precautions were adopted for the walls of the docks, which were faced with freestone and backed in with brick: a row of sheet-piling was driven along the whole length of the footing, to prevent the water from acting upon any portion of the foundation.

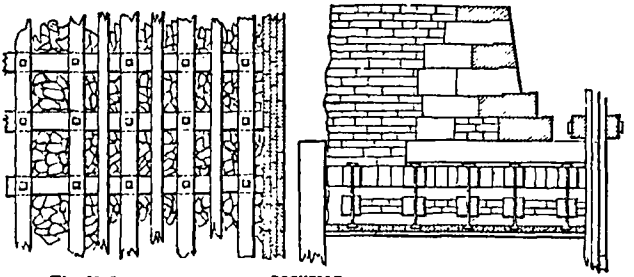


Fig. 2820. ROCHELLE.

Another system of holding in the upright fenders is by irons worked into the solid wall, or they may be made to pass round a row of horizontal timbers, halved into the upright at the levels of high and low water.

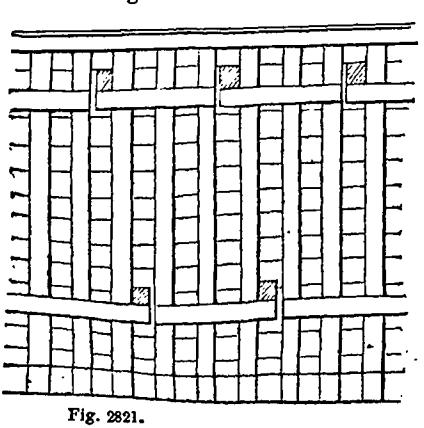


Fig. 2821.

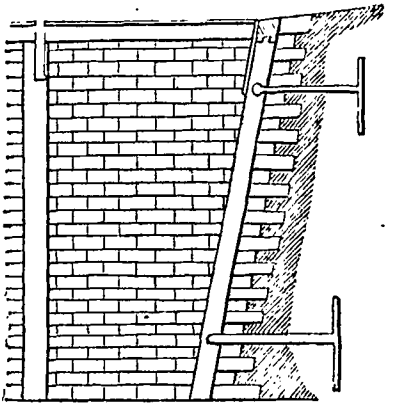


Fig. 2822.

Stone facings backed with brick, when made to batter, afford the best protection to the sides of a dock or pier that can be devised: upright fenders of oak or fir secured by iron

ties may be placed at regular distances, for protection against the vessels, and rings may be inserted to make them fast. Sheet-piling should never be omitted to protect the foundations.

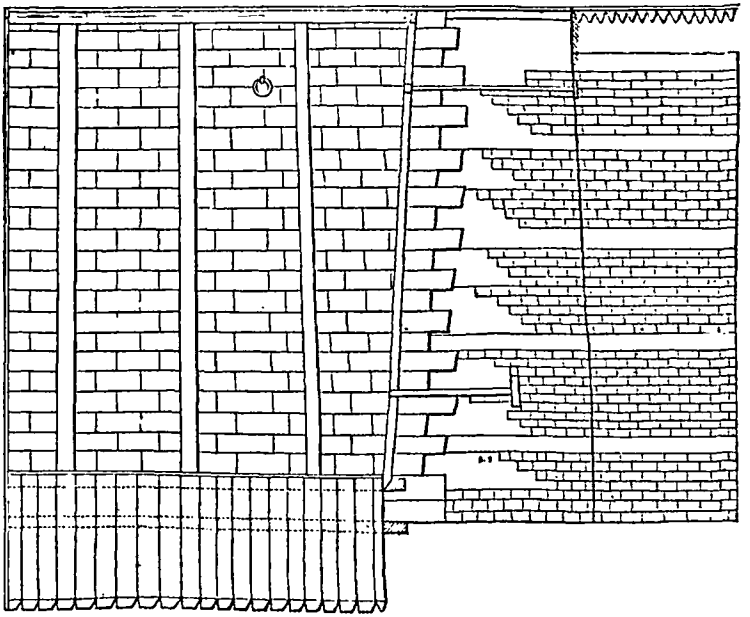


Fig. 2823.

Where the foundations are chiefly composed of sand. or of an earth liable to slip, it is absolutely necessary to continue a row of sheet-piling to the stratum beneath it: to drive the piles a crab engine with a ram of 10 cwt. may be made use of, with a fall varying from 8 feet to 18 feet, or 12 feet on an average, which will generally drive an inch at each stroke.

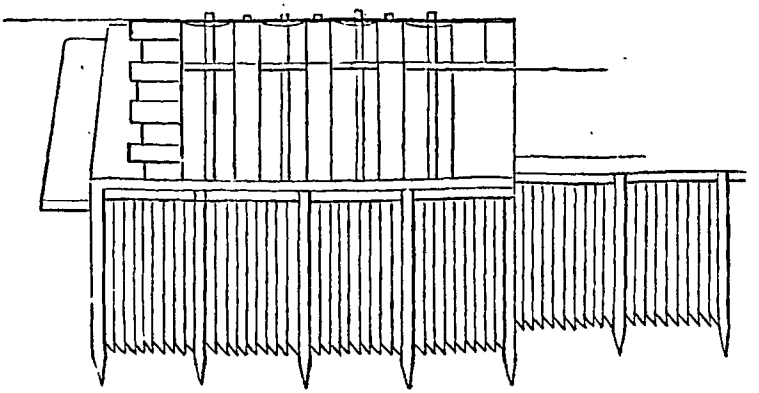


Fig. 2824.

Platforms of carpentry, when laid upon the heads of piles, should be perfectly level, and boarded through in the longitudinal, as well as transverse, direction; taking proper care first to drag between the heads of the piles, and render the intervals solid, by throwing in loose stones or a mass of concrete.

When foundations are upon gravel, it is very necessary that they should be consolidated, either by dropping in large stones, or by piling, and afterwards laying over the whole a timber platform, at such depth below low water that it cannot be affected by the tide.

In some instances, in forming sea walls, timber and stone may be introduced together, and particularly when the banks are loose and subject to slip, or are acted upon by the land-springs. A stone wall carried up in front of the work, supported at the back by strong wooden piles strutted and braced, and afterwards filled in with concrete, or puddled

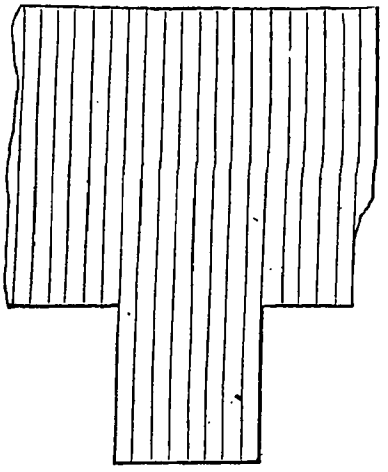


Fig. 2825.

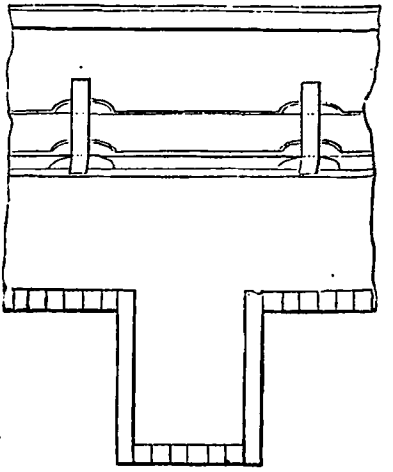


Fig. 2826.

with clay in the manner of a cofferdam, will have great strength, and resist any force to which it may be opposed: a row of sheet piles round the face of such walls, as well as the buttresses, prevent any irruption, and planking the whole foundations over binds them into one entire mass. It is sometimes advisable in face of a cliff to form a temporary defence, by driving in double rows of piles, and filling up the space between with clay or earth im-

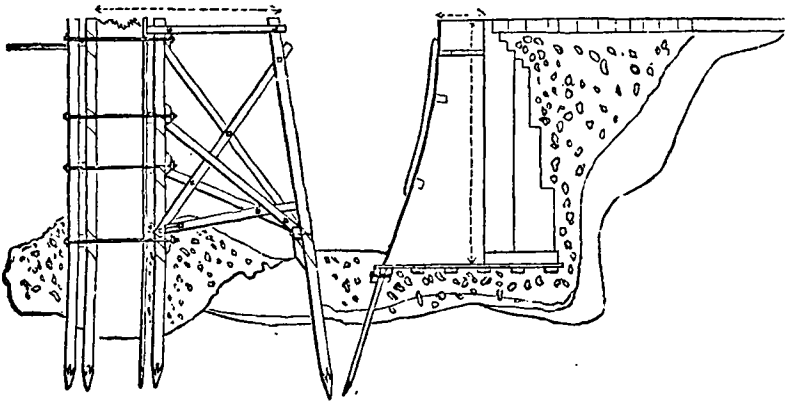


Fig. 2827.

pervious to water: the weight acting against such a dam should be always resisted by a timber framing on the opposite side. When a length has been put together and secured by iron bolts, they may be drawn, and the same framing advanced another length, and so continued until the entire shore is out of danger.

CHAP. XXVII.

CANALS AND RIVER LOCKS.

CANALS are to the inhabitants of a country what seas are to nations; they equally serve to assist the wants of society and benefit commerce. The great navigations extend over the whole globe, and transport the products of all nations and climates where they are in excess to where they are most needed, which, by means of the internal canals, are distributed to the various districts in smaller craft, enabling these latter at the same time to maintain a continual and economical interchange of whatever may be required either for food or manufacturing purposes. But the formation of a canal is frequently attended with great difficulties; and all the talent of the engineer is called forth in overcoming obstacles apparently insurmountable, but which by a careful survey and patient investigation will generally be vanquished.

In commencing a canal the first consideration should be directed to the quantity of water that will be required, and from whence it is to be supplied, the means of keeping the bottom clear, the construction of the sluices, and the distribution of the slopes of its bed.

The water is usually collected from springs or rain, or derived from some neighbouring river; and in whatever way the supply may be received, it is incumbent on the engineer carefully to examine not only the nature of this supply, but also to ascertain the quantity lost by evaporation and absorption: should it be drawn from a river, it is commonly effected by constructing a weir across it, and after damming up the stream, admitting a portion into the canal, and, if a continuance of a navigation be not practicable in the bed of the river itself, the stream must be traversed by other dykes or weirs, the height of which, as well as the depth of water required, will demand great consideration. The smallest possible quantity consistent with the purposes of navigation should be admitted, in order to keep down the height of the sluices, banks, and dykes, all of which are affected by the pressure of an increased body of water; and it is highly necessary to make such arrangements that no injurious consequences shall arise from the floods, which occasionally swell the waters in the rivers of supply. Another important precaution is preventing any deposit of gravel or other matters held in suspension by the water, whilst it is permitted to move rapidly forward: could it be freed from these before their introduction into the canal, much manual labour would be saved, and the fatal effects arising from the miasma produced by throwing out the mud on the banks be prevented.

The common method adopted in Italy for cleansing the canals is by sluicing: bottom or ground sluices are constructed in the banks nearest to the river of supply, having their sills laid at a considerable depth below the bottom of the canal, over which the water, being occasionally allowed to fall, acquires sufficient velocity for a considerable distance beyond the opening of the sluice to detach any substances that may have lodged at the bottom of the bed: numerous sluices distributed throughout the whole length, placed at distances where they can be made to operate after the action of those below has ceased, have successfully moved large quantities of gravel deposit.

When the supply is first accumulated in a large reservoir, the deposit may be made to take place before the water is used for the purposes of navigation: the expense attending this method has been its great objection: wherever gravel and coarse substances are brought down by the river that feeds the canal, their diffusion should be as much as possible prevented; this is sometimes done by opening an ample bottom gate immediately above the sluice, and making the platform slope considerably towards the mouth of the outlet; by keeping up the sill of the first gates, a little above the level of the outer platform, when they were opened the gravel would be prevented from entering; but this must be guided by circumstances, as no obstruction must be allowed to the navigation when the waters are low in the canal.

Level Cutting. — This term is applied to an excavation when the banks are made of the earth taken out; it is the most economical method, and consequently the most generally practised, the breadth and depth of the bank being of course dependent on the strength required. It often occurs that a canal is cut on a hill, and a bank is made only on one side: the work is then exceedingly simple, and called *side or oblique cutting.*

The Centre of Cutting is that point in a transverse section through which, if a line be drawn representing the surface of the ground, the part for excavation will be found equal to that of embankment. To apply this to a canal on the side of a hill with parallel slopes, where one bank only is required, let A B C D be the section of the intended canal, C D E G F that of the bank; to find the centre of cutting, continue the lines B C and D E to G and

A; draw the perpendiculars C*m*, D*n*, and the diagonals A G, *mn*, intersecting at *p*: through *p* draw the parallel *spt*, and bisect it in *o*, which is the centre of the cutting, through

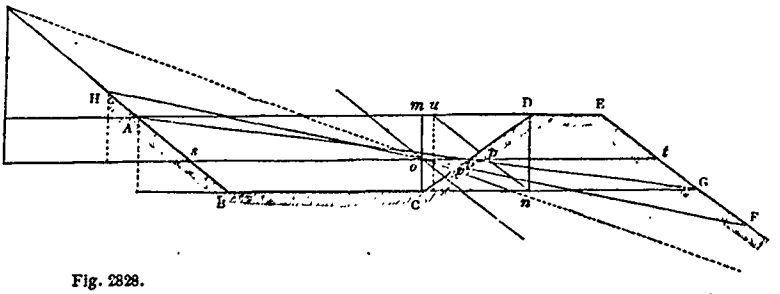


Fig. 2828.

which, if any line H*o*F be drawn cutting the slopes A B and E G produced, H B C*w* will always be equal to *w* D E F; for *mn* D = C D*n*, therefore *mn* G E = C D E G. But *mn* G E = *s* B G *t* = C D E G, and taking away C*v t* G, we have *s* B C*v* = *v* D E*t*, and the triangles H*so* and *ot* F are equal, having equal angles, and the side *so* = *ou*; therefore the sum H*so* + *s* B C*v* = *ot* F + *v* D E*t*, and taking away the part *owv*, there remains H B C*w* = *w* D E F; therefore, as the total breadth of the canal and bank is to the breadth of the bank added to the base of one slope, so is the depth of the canal from its surface to the depth below the centre of cutting, which is also the centre of cut and cover, for a line staked out at the level of the centre of cutting will show the middle of the land required for the canal.

A canal with a bench or towing-path on the upper side. Let *a* A B C D E G be the profile of the canal and bank; take D*d* = *a* A, and draw *ab* and *cd* parallel to the slopes;

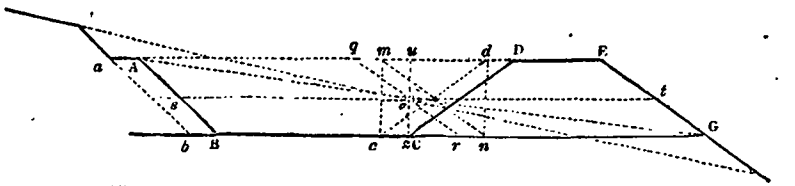


Fig. 2829.

the section *a* A B C D E is converted into *abcd* E, which comprises the towing-path: draw the lines *a* G, *cd*, and *st*, and the middle *o* will be the centre of cutting. The distance from centre of canal is equal to *uq* + D E − *a* A.

E*q* : E*m* : : ½ *mc* : *oz*; that is, as *a* E : E D : E D + D*d* + *dm* : : *mc* : *oz*.

To reduce the section A B C D E F with a second bench or path E F, to the equivalent section A B I K F, with one bank only, but wider and shallower, the banking cut down, and

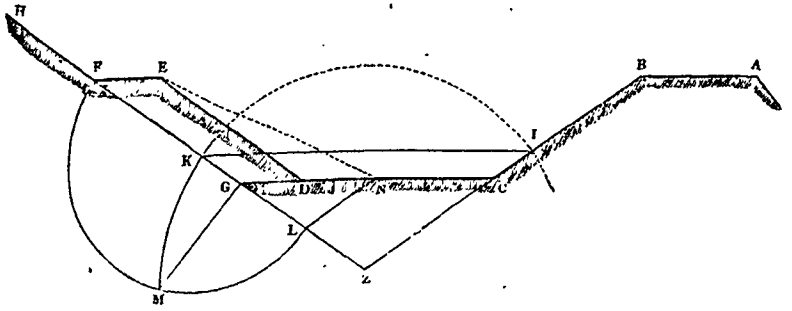


Fig. 2830.

filled in to the bottom. Produce B C and H F to Z, and C D to G; make D N to equal D G; draw the parallel N L; on F L describe the semicircle L M F; make Z K and Z I equal to Z M, and draw the parallel K I, and the figure is complete.

To find the Lines of Level Cutting, when the section of a canal has two banks, and the slopes are made all equal. The section A B C D must first be reduced into A H K E, and

the centre of the cutting must be found; each slope must be prolonged to meet in V: draw the perpendicular N V; with the radius N V and N as a centre, cut E A in *p*, make V*a* equal *p* Q; then through *a*, parallel to E A, draw M L, which is the line of level cutting.

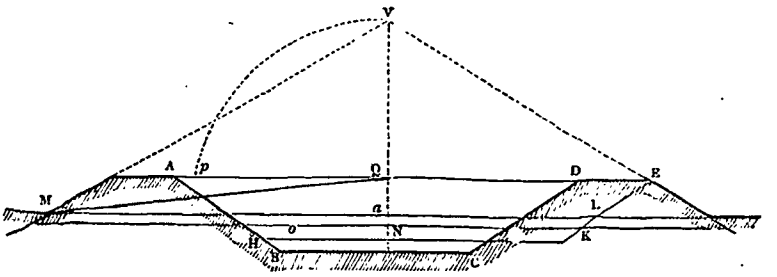


Fig. 2831.

To find any Line of Oblique Cutting. — Find the line of level cutting, produce the slopes to meet in V; draw the perpendicular V I; from L draw L N with the given slope of the

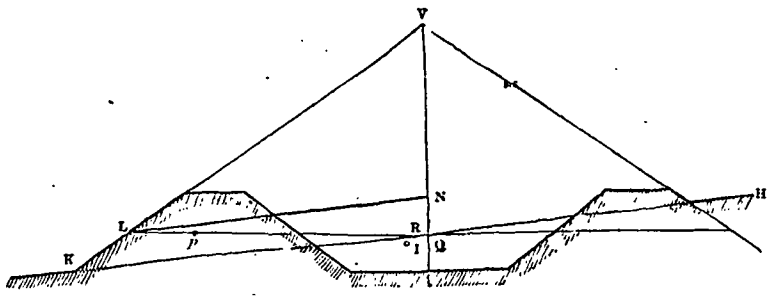


Fig. 2832.

ground, cutting V I in N, making N*p* and *p* Q equal to V I, and V R equal to *p* I: through R draw K R H, which is the line of oblique cutting sought for.

Theory of Locks. — Locks with gates for the purposes of navigation are of modern invention; those of the Canal of Martezana, in Italy, already mentioned at p. 186., were the first executed: their date is not more than 386 years since; they were the model from whence all others have been taken, nor does it appear that any great improvements have been made, nor have any rules been given for their proportion: the only difference in the various locks hitherto constructed consists in the greater or less width and height, for the purpose of containing one or more boats, isolating or uniting several chambers, and making the side walls either straight or curved. Belidor has treated on this matter, and given an account of various works; he has, however, only mentioned the proper projection for the pointed sills, and the strength of the timber necessary for the gates, and endeavoured to show that no advantage is derived from a curvature in their plan.

The least Length that can be allowed between the Locks should be such that 12 inches of depth, over and above what a loaded boat will draw, will only lower the water 6 inches without the navigation being interrupted; and if it be required to draw the contents of each lock from the interval above, the distance for the locks must be so regulated that the quantity of water expended by one should not lower that of the upper interval more than 6 inches at most; thus the distance should be greater in proportion to the contents of the chamber of the locks and the width of the canal; that is to say, when the chambers are large and the canal is narrow, the distance between the locks should be greater. Chambers 110 feet in length between the gates by 17 feet in width, as those of the canal of Briare, contain 1870 superficial feet; therefore 11,843 cubic feet when the fall is 6 feet 4 inches, 15,859 cubic feet when it is 8 feet 6 inches, and 19,635 cubic feet when 10 feet 6 inches. If the canal be 48 feet in width, at 3 feet below the ordinary level of the water, the length of the interval should be 446 feet, in order that the expenditure of locks of 6 feet 4 inches of fall should not lower the water more than 6 inches; this length should be 607 feet when the locks are 8 feet 6 inches of fall, and 755 feet when they are 10 feet 6 inches: the distance then between the lower gate of one lock and the upper gate of the other should be always about 624 feet for ordinary canals. If two locks of 8 feet 6 inches fall were only distant

160 feet, the water drawn from the interval, for the purpose of mounting the boat, would lower it nearly 26 inches, and there would not remain sufficient to keep it afloat; consequently, it would be necessary to draw a lockful from the upper interval, and then a second to cause it to rise, whilst only one would be required if the locks were at a sufficient distance.

This example will show the inconvenience of having locks too near each other, which is still further increased when they are contiguous: it frequently happens that several boats arrive together in the same interval, particularly where the bargemen stop or sleep, and that no water may be lost, the interval where they stop should be sufficiently long to admit more than one; if circumstances will not permit this, a greater width must be given, that the lockfull which the rising boats draw from the interval should not cause the water to lower so considerably as to prevent their floating, or the descending boats force in such a quantity as to make it run over the gates: if the interval has only the ordinary width of 48 feet, it should be 6398 feet in length, so that ten rising boats could stop, if none were descending at the same time, otherwise a part of the water must be drawn from the other intervals to keep them afloat: if there were as many ascending as descending boats, this need not be so great; but this observation proves that in forming a canal it is necessary to have basins at those situations where boats are required to stop any length of time.

Quantity of Water expended by Boats in traversing a Canal.—It was the opinion of MM. Gabriel and Abeille, that the passage of a boat through the whole length of a canal always cost twice the quantity of water necessary to fill a lock: Belidor thought the same, and it is still the common opinion. M. Thommason has nevertheless maintained that this idea is erroneous, and that when one boat passes several locks one after another, the second boat only expends two locksfull in its whole passage; but when they pass alternately, one up and the other down, that it costs as many locksfull as there are locks in the ascension of each boat. He founds this assertion on two statements, one of M. Caligny, the other of M. Regemorte, asserting that the expenditure of the water is the same, whether contiguous or separated; but this distinction not having been sufficiently examined, a second error has been committed; but it is undoubted that when locks are contiguous, they often expend more than two locksfull; and it has not been remarked that when the locks are more than 640 feet apart, they often expend only a single lockfull for the whole journey. When locks are distant from each other, and the boats pass alternately, one up and the other down, the boat which passes after the first frequently finds in mounting all the locks empty, and to fill them it must draw a lockfull from each interval and one from the starting point; in descending, as it finds the locks full, it does not draw any from the starting point, consequently it will only expend a single lockfull in its whole voyage.

When the locks are distant from each other, and the boats follow, the second boat will find all the locks full going up, and to ascend it must first empty all, and then fill them with water drawn from the intervals, and the highest from the starting point: in descending, all the locks will be empty, and the first lock will be filled with water from the starting point, which will serve to fill all the others, so that this boat will expend two locksfull in its journey.

When the locks are so near each other that the water of one taken into the interval between the two diminishes the depth of this interval sufficiently to impede the navigation, or when the locks are contiguous and the boats pass alternately, the second boat in ascending finds all the locks empty, and as it cannot draw water from the intermediate intervals from the contiguity of the locks, all are filled with water from the starting point. Thus in ascending each boat expends as many locksfull as there are contiguous chambers; in descending, all the locks being full, no water need be drawn from the starting point, consequently in a whole journey as many locksfull will be expended as there are contiguous locks in ascending. When the locks are contiguous, and the boats pass each other in succession, the second in ascending will find all the locks full, and to enable it to enter the intervals, it must empty them successively to fill them with the water from the intervals, except the last, which it fills with water from the starting point; in descending, another lockfull is taken from the starting point, so that in this case two locksfull are taken from the latter.

Although the four above cases contain the whole theory of the working of locks, it may be remarked that if two boats meet at the starting point, and two others before or after the starting point, the four will expend five locksfull; if two boats meet at the starting point, and the two following meet there also, the four will only expend four locksfull; if the two last boats that have passed meet before or after the starting point, and the two succeeding meet also before or after the starting point, then they will only expend four locksfull, had the first come in an opposite direction to that which had passed previously, and five if it had come in the same direction; and it has been generally observed, that a boat always takes a lockfull from the starting point to ascend, but that it often does not take any to descend on the other side, consequently, when there are no contiguous locks, the boats will only expend a lockfull for their whole journey, when they pass the starting point al-

ternately, one going up, the other down: in like manner, where there are contiguous locks, the boats will expend in their journey as many locksfull as there are contiguous locks in ascending; when one boat follows another, it will expend two locksfull, whether the locks are contiguous or isolated. It must be remarked that the passage of those boats only can be considered relatively to the locks which join the starting point: when the locks are not contiguous, and their fall is equal, which happens in the lower intervals, it has no influence on the expenditure of water, especially when the boats do not stop any length of time; in giving 640 feet length to each interval, it is evident, when two boats follow each other, they will never be together in the same interval, since whilst the second passes the lock, the first will have time to pass the interval and enter the following lock; thus two boats cannot meet in the smaller intervals, except when one ascends and the other descends, and in this case, as one takes a lockfull from the interval, whilst a second pours one into it, consequently the water does not diminish or increase in it. It must be observed that we can never have above a lockfull, more or less, in an interval, unless several boats remain in them together, which should be avoided when they are small; further, when the contiguous locks are distant from the starting point, it often happens that the lockfull is not immediately taken; but when there is no second quantity of water before the contiguous locks, it is always the starting point which furnishes that of the canal above them.

Locks to contain several boats are successfully employed where water is abundant. In forming them the side walls may be dispensed with, the sides of the chambers only being laid with stone to a proper talus; some of those chambers may contain four boats, others a large and a small one; at the ingress and egress there usually are two pairs of gates, one small and the other large: locks to contain two boats are either double the length or the width of the chamber. The second plan is the least expensive, the length of the chamber walls in this case not being greater than for the more simple locks; but the first has the advantage of receiving a third pair of gates in the middle of its length, so that one or two boats can pass at pleasure; the length of the chamber is also varied, by placing more than two pairs of large gates, enabling boats of different dimensions to pass together or separately, without expending a greater quantity of water than would be necessary for each boat. To make the chamber of a sufficient length for two ordinary-sized boats, a gate is placed in the middle of its length, and another at the necessary distance for the larger boats; the rest of the length is then available for smaller: it is, however, seldom necessary to make provision for the passage of boats of various sizes, as there is no advantage in two boats passing at once; when the chamber is constructed of masonry, twice as much water is expended for the passage of two boats as for one, consequently twice as much time is employed in filling a lock for two boats as for a single one; there is therefore no gain either in time or the quantity of water, and the expense of construction is considerably augmented.

The chambers of this kind of locks are sometimes formed by a slope of earth only, without a facing of masonry; but they expend much more water, consequently take a longer time to fill, and are less advantageous on account of the time lost by the boats having to wait for each other: should one arrive alone it must remain until a second comes up before it can pass the lock, or as much water must be expended for the one as would be required for two, and of course this inconvenience is increased when the chamber is made to contain four boats.

Form to be given to the Chambers of Locks. — The most convenient is the parallelogram, a little wider than the boats that require to pass, and sufficiently long to admit of the gates being moved with facility. The chambers of the canal of Languedoc are of an oval form, to give greater strength in resisting the banks contiguous to them; but as this causes an increase of expense in construction as well as in the quantity of water necessary to fill it, it will be useful to enquire if, in avoiding one inconvenience, a greater is not produced. The oval chambers of the canal of Languedoc contain an area of 3636 feet, whilst if the side walls were parallel, they would only be 2248 superficial feet: thus the expenditure of water in the oval chamber exceeds more than a third that of the parallelogram, the proportion being about 5 to 3: the inconvenience is considerably increased by want of water, which frequently occurs. Another result of the oval form is that the passage of the lock is also longer than in the rectangular; in the same proportion the expense of the timber platform is also increased: it is, however, certain that a curved wall is stronger against a pressure of earth than a straight one, and if the cost of masonry requisite to give the same strength to a straight wall is greater, the expense is compensated for by the diminution of the cost of the timber platform, which is two-fifths stronger. It is very essential to prevent the filtration of water through the side walls, and the best method to effect this is to place on their thickness a lining of beton, or of brick laid in cement, which will be impervious to water; but as this will destroy the bond, a greater thickness of wall is requisite; thus there are many circumstances where it might be necessary to give to curved walls as great a thickness as to straight. The thickness of straight walls which support earth should be a third of their height, whilst those which resist the thrust of water should be one-half; if the walls of the

chambers of locks have a thickness relative only to the thrust of the earth, they may give way when the earth is put in motion, which often occurs from a slight filtration behind the wall. Gauthey has a rule for finding the thickness to be given to the wall of a basin intended to support water throughout its whole height, and in the chambers of locks it must be remembered that the thrust of the water against the vertical surface is equal to the product of these surfaces by half the height of the water: call h the height of the wall, x = its thickness, supposing its length to be 1 metre, the acting power will be $1000 \times \frac{1}{2} h^2$: supposing the cube metre of water to weigh 1000 kilogrammes, and the centre of impression of this thrust

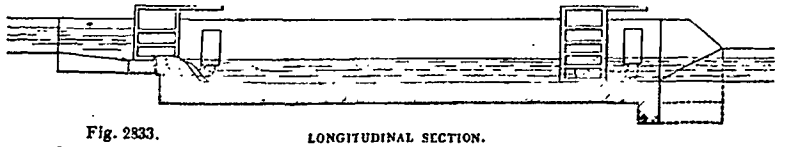


Fig. 2833. LONGITUDINAL SECTION.

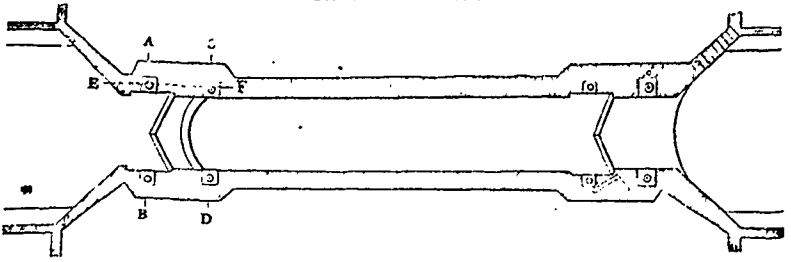


Fig. 2834. PLAN OF LOCK.

being at a third of the height of the wall, the arm of the lever of the acting power will be equal to $\frac{1}{3} h$.

The resisting power will be the wall itself $= hx \times 2000$, supposing that the cube metre of masonry generally weighs 2000 kilogrammes. The arm of the lever will be half the thickness of the wall $= \frac{1}{2} x$, consequently the momentum of the acting power will be $1000 \times \frac{1}{2} h^2 \times \frac{1}{3} h$, and that of the resisting power $2000 \times \frac{1}{2} h x^2$; and as in the state of equilibrium these two powers should be equal, we shall have $167 h^3 = 1000 h x^2$, from whence we have $x = \sqrt{0{\cdot}167 h^3} = 0{\cdot}41 h$: but, as something should always be allowed above the equilibrium, by adding $\frac{1}{10}$, we shall have $x = \frac{1}{2} h$ nearly: hence it is evident that the thickness of a wall intended to support water should be equal to half the height of the water which acts against it.

The length and width of chambers of locks must necessarily be regulated in conformity with the boats used on the canal; these are generally longer and narrower than those on rivers, where the shallows which occasionally occur require flatter bottoms to be given them: the letters A B, C D, E F, refer to the sections through the several parts of the lock chambers. With regard to the length of the chambers, it should be such as to enable the gates at the lowest ends to open and shut easily; if the rudder of the boat cannot be unshipped, or occupies any portion of the length of the chamber, then the chambers must be made sufficiently long to prevent them from interfering with the opening of the gate, on which account the most proper rudders for navigable canals are those like broad oars, which can be taken out whilst passing through the locks. The height of the water in the intervals is regulated by the mean height of the waters of the river which communicate with the canals: it is, however, customary to allow the latter a sufficient height of water to receive boats of the same tonnage as those which navigate the river; another advantage

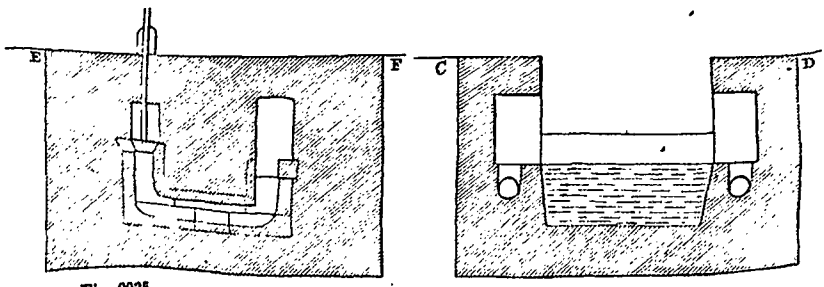


Fig. 2835. TRANSVERSE SECTIONS. Fig. 2836

in giving an extra depth of water to canals is the greater ease with which the boats can be drawn, the weeds at the bottom causing less inconvenience, and the evaporation being of course less than in a shallower body of water; in summer also, when the boats can only carry half a load, two loads may be put into one boat, and the transport rendered less expensive.

The quantity of water expended by locks is found to be in direct proportion to the height of the fall, and the time employed in going through them, and the expense of construction nearly in the same proportion; this is greater as the locks are least elevated, because they are more in number, but the increase is not in proportion to the number.

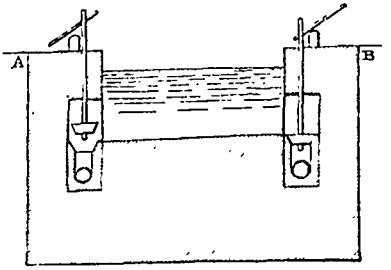


Fig. 2837. TRANSVERSE SECTION.

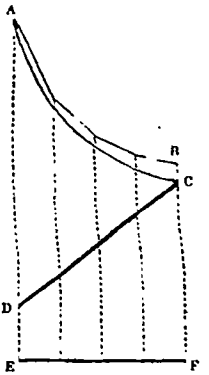


Fig. 2838.

To render these relations evident, trace the curves A B, A C, and the line D C on the axis E F; the ordinates of the first mark the relation of the time employed in going through the total of the locks of different falls: those of the second mark the relation of the expense of construction, and those of the line D C mark the quantity of water which they will expend.

It may be concluded that when there is a great deal of water in a canal, the locks may be high, because the saving in the expense is a great consideration, less time being required to go through them, and the wages of the lock-men reduced.

The Talus. — It is by no means advisable to make the walls of the lock chamber strictly perpendicular: some inclination, or talus, is always preferable, particularly at the back, whence resistance is required against the thrust of water; and as its filtration is another point of importance to be guarded against, a greater thickness is necessary at the bottom than at the top of the wall, that filtration being greater in proportion to its height. The walls should, however, be perpendicular towards the interior of the lock, at least in that part where the boats mount and descend; the lower part may have the same talus as that usually given to the boats. The least thickness for the walls at the level of the water is 4 feet 3 inches, in order to allow for a course of beton in cement or of brick, as a protection against the filtration of water: as a general rule, the thickness should be equal to half their height, and as the walls become more lofty, their foundations must be spread out in proportion.

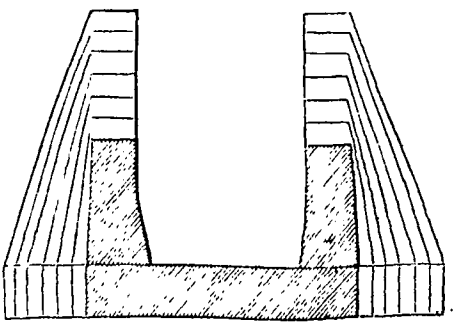


Fig. 2839.

Inverted arches have been introduced with considerable advantage to form the profile of the wall of lock-chambers; where there is a good foundation they may commence with a considerable batter or inclination, rising gradually in a curved form, finishing at the top with a perpendicular face; such a wall resembles an arch, from its having the joints and beds of the several stones made perpendicular to their face, which also prevents them from sliding on each other: the triangle of earth, supported by the back of the upright retaining wall, may be regarded as a wedge, of which its own gravity is the acting power, and it is only supported by the re-action of the inclined plane of earth, and the back of the wall, each of which acts perpendicularly to its plane. The breadth of such retaining wall must be always proportionate to the height, and to be of equal specific gravity with the earth, its breadth should be more than $\frac{1}{2}$ of its height. The specific gravity of walls built of brick or stone is a trifle more than that of the earth they support, therefore the dimensions may be slightly diminished.

Dimensions of the other parts of the Locks. — The chambers have also walls above streams, called shoulders of defence, shoulders below stream, or discharging walls, wing-walls above and below, and return walls. The thickness of the shoulders of defence should be less than those of the sides of the lock; 3 feet 2 inches will be sufficient, or half the height of the water; but on account of the foundations, and above all, of the beton to be placed in the centre, it is better to make them, as well as the wing-walls above stream, 4 feet 3 inches: their length should be at least equal to the width of the gates; an additional 1 foot 8 inches will form the necessary projection for the recess, into which they will fall when opened.

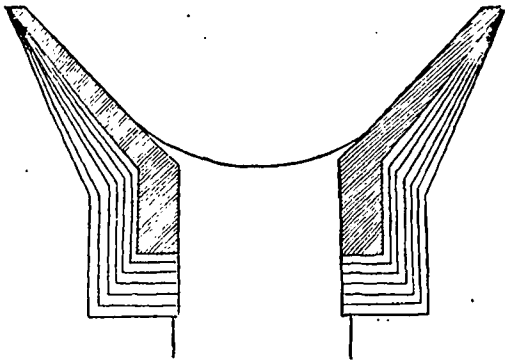


Fig. 2840.

The return walls of the wings are necessary, to prevent the water from working behind the body of the lock, but as the back walls are furnished with a lining laid very low, it will be sufficient to give 25½ inches of thickness to the return walls; their length must be proportionate to the quality of the soil with relation to its permeability to water or otherwise. The lining may be continued further than the length of the walls; this portion cannot be too well protected both before and behind, nor can the wing, the shoulder wall, and the back of the fall.

The shoulders of discharge must not be regulated by the height of the water, as it seldom rises to half that of the walls, which should be regulated by the thrust of the earth, and consequently the thickness may be equal to one-third their total height, if they are perpendicular on both sides; but it is better to make a retreat or set-off of 12⅓ inches at the back, level with the water, and to give the lower part an increased thickness: it is not absolutely necessary to use any beton, but it would be unquestionably advantageous. The length of the shoulders of discharge should be relative to the height of the water in the chamber of the lock, the gates down the canal supporting all the weight of water, which is sent back against the heel-posts, which in their turn rest entirely on the shoulders; consequently their length must depend on the resistance necessary for opposing this thrust.

To ascertain this resistance it must be remembered first, that if instead of gates a wall were substituted, it must have the same thickness as the longitudinal walls of the chamber of the locks, that is to say, a third of the total height of the gates, for although the water of the lower interval resists the thrust of the upper, it must not be taken into account, the resistance being small with regard to the thrust, not only from the weight of water being much less, but from the centre of impression being very near the point of support; there is, therefore, but little action to resist the centre of impression of the water on the chamber, which is much higher.

Secondly, the two gates may be regarded as a single inflexible sluice, resting against the heel-posts and the sills.

Thirdly, as the thrust is considerable, it is to be presumed that if the masses constructed behind the heel-posts of the gates were not sufficiently strong to be in equilibrio with it, a disjunction would take place in the masonry, the tenacity of which alone is not capable of very great resistance, particularly if the masonry be lately constructed.

Fourthly, this disjunction will take place in the line of an angle more or less open, according as the stones are shorter or longer in the direction of the headers; if they were about as long again as wide, the angle would be one of 50°, and its base would be one-half smaller; if the lengths were equal to the widths, it might be even less, as the masons usually bed the stone in the direction of the face of the wall; the filling-in being almost always of small stones, so that the facing only would form a resistance.

Fifthly, in order to place the resistance above the equilibrium, the tenacity of the mortar must not be taken into account, and the base of the angle of rupture must be considered as equal to half its height. When the weight of water, instead of acting against the gates, acts against the wall, it has been already shown that the thickness of this wall should be equal to half the height of the water. Let l be the width between the hanging-posts, h the height of the water, the cube of this wall will be $\frac{1}{2} lh^2$; the arm of the lever will be $\frac{1}{4} h$, thus its energy or momentum $\frac{1}{8} lh^3$. Let the shoulder wall be A H D C; draw A E in such a manner that E B shall be equal to $\frac{1}{4}$ A B, naming B E a, B A will be equal to $2a$; let x be the length B C sought for. It is evident that the mass A E D C, and that which

is opposite, must form a resisting power, the energy of which should be equal to that of the wall, which has been supposed in the place of the gates. Each of these masses is composed of a triangular prism, the base of which is A B E, and of a parallelepiped, the base of which is B C D E; the cube of the triangular prism is a^2h; its arm of lever is $\frac{2}{3}a+x$, thus its energy will be $\frac{2}{3}a^3h+a^2hx$. The cube of the parallelepiped is ahx, its arm of lever is $\frac{1}{2}x$, thus its energy is $\frac{1}{2}ahx^2$, so that the energy of this resisting mass is $\frac{2}{3}a^3h+a^2hx+\frac{1}{2}ahx^2$: the other mass being the same, the total energy will be $\frac{4}{3}a^3h+2a^2hx+ahx^2$, and as that energy should be equal to that of the wall, which we have supposed in the place of the gates, which is $\frac{1}{6}lh^3$, we shall have the equation, $\frac{4}{3}a^3h+2a^2hx+ahx^2=\frac{1}{6}lh^3$, or $x^2+2ax=\frac{lh^2}{8a}-\frac{4a^2}{3}$; whence we have $x+a=\sqrt{\frac{lh^2}{8a}-\frac{a^2}{3}}$, and as $l=5{\cdot}2$ metres, we shall have $x+a=\sqrt{0{\cdot}65\frac{h^2}{a}-\frac{a^2}{3}}$

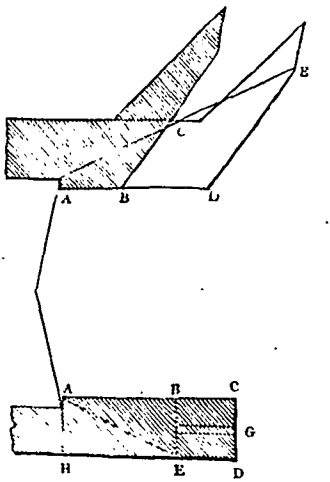


Fig. 2841.

If the thickness of the wall is equal to a third of its height, or $a=\frac{1}{3}h$, we shall have $x+\frac{1}{3}h=\sqrt{1{\cdot}95h}+\frac{1}{27}h^2$, or $x+\frac{2}{3}h=\frac{1}{3}h+\sqrt{1{\cdot}95h+\frac{1}{27}h^2}$: if the thickness of the wall be made equal to half of its height, we should have $a=\frac{1}{2}h$, and the equation would become $x+\frac{1}{2}h=\sqrt{1{\cdot}30h+\frac{1}{12}h^2}$, or $x+h=\frac{1}{2}h+\sqrt{1{\cdot}30h+\frac{1}{12}h^2}$. By means of these two equations, tables have been calculated by Gauthey for the length of the shoulders.

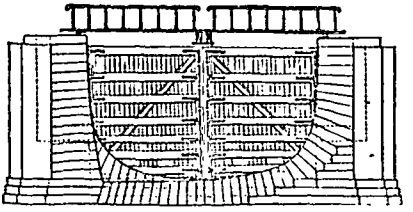


Fig. 2842.

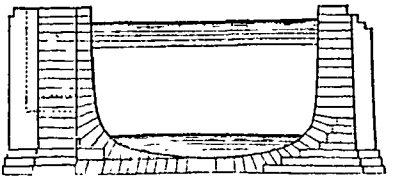


Fig. 2843.

CHAMBER WALLS.

It may be remarked, that on giving to the thickness of walls half their height, their length need only be one-third, in order to have the requisite resistance, although their cube is one-third greater. Supposing the rupture to take place from A in H, the length would be less, but not considerably so; allowance must be made for the set-off of 12 inches below the water, which increases the resistance of the wall, and puts it above the equilibrium. These shoulder walls are generally terminated by expanded wings, with an angle of 50°, on which it must be observed that, if the shoulders were shorter, the wing-walls would not be of much service in assisting the former to support the thrust of the water, because the fracture would take place on the facing of the wing-walls, and there would only be a small mass of masonry, A B C, to resist the thrust, whilst when the shoulder pieces A, D are long, the wing-walls may entirely resist the thrust, since the direction of the rupture A E abuts at their extremity. The length of these walls should be equal to the radius of the gate, that they may open entirely and with facility, as the lockmen must walk on them to perform their operations.

The Wing-walls to the lower Gates should have a thickness equal to one-third of their height, on account of their supporting the earth; steps may be added to them when they support a talus, giving convenient access from the platform of the lock to the upper part: these walls generally terminate in the banks of the canal, and perpendicular return walls may be formed following their direction; but they are not so essential as in the upper part, because the filtration of the waters from the lower interval is not so dangerous as that from the upper, or from the chamber of the lock.

Masses are generally constructed behind and below the hanging-posts, to receive the anchors which retain the collars, and to make them enter deeply into the masonry, in order that they may have a firm hold; but they are also essential in preventing the water from insinuating itself at the back of the side walls, and forming a disjunction between the earth and the masonry, where a void would allow the water from a chamber to percolate, and ultimately cause the walls to give way: to prevent this alone a great thickness would not be requisite; but it must be increased on account of the anchors, two being attached to

each collar forming an angle, generally in a line with the pointing sills; but it is better that one should be pointed up, and the other down the stream, to resist the thrust of the water on one side when the gates are closed, and on the other to check the weight of the gate when in movement.

Counterforts are sometimes introduced in the length of the chamber to resist the thrust of the water, in which case the thickness of the side walls might be diminished, which would be a considerable saving of masonry; but on account of the filtration, which cannot be too carefully guarded against, it is better to make the walls of sufficient thickness, and to dispense with the counterforts.

The wall which constitutes the fall in the lock is usually perpendicular, though a talus may be given without any inconvenience to the boats: when the canal is dry, and requires to be filled, the water flows from the top of this fall on to the platform, and tends to injure it; to remedy this as much as possible, the fall of the lock should have a curve of uniform descent; the direction of the running water then be-

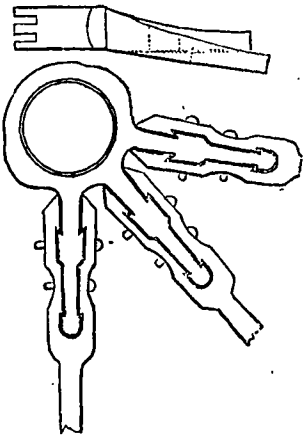


Fig 2844. GATE ANCHOR.

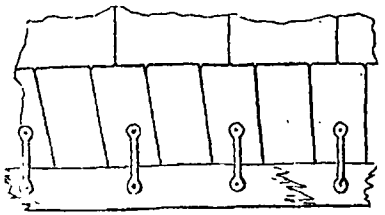


Fig. 2845.

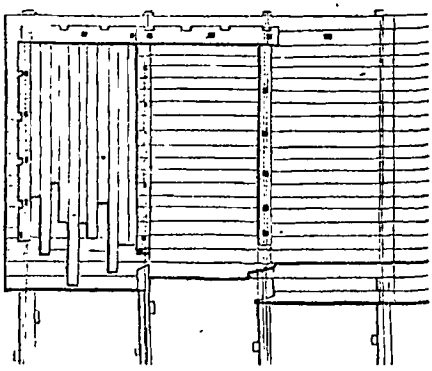


Fig. 2846. SCOURING SLUICE PLATFORM.

coming horizontal at the end of its fall, it has much less action against the platform than when its direction is inclined.

When the pointed sills are of stone, it is advisable to make the fall of the lock concave on the plan, in order that the key of the sill may have a sufficient section to be solidly based. The thickness of the walls which form the fall is usually considerable, but this is unnecessary; the same as that of the side walls is quite sufficient.

The Platform. — This construction is of the greatest importance, being that part of the lock most difficult to keep in repair, and most often requiring it; they were formerly made of timber, but this is to be avoided as much as possible, timber never uniting well with masonry, and a film of water almost invariably insinuating itself between the planks and the masonry, between the heads of the piles, the force of which in relation to its weight is considerable, making the platform yield, disuniting the framework, and preventing the easy working of the gates: the shock of water from the upper interval is, however, less injurious to timber than to stone, and if good stone cannot be procured, to resist this effect, a platform of cross planks over that of rubble might be formed on pieces of timber encased in the walls, but only in that part where the shock takes place. Where it is possible to obtain them, large flagstones are preferable for the surface of the platform; and in order that they may be solidly bedded, each row should be worked with dovetails into a course of freestone placed upright, which would

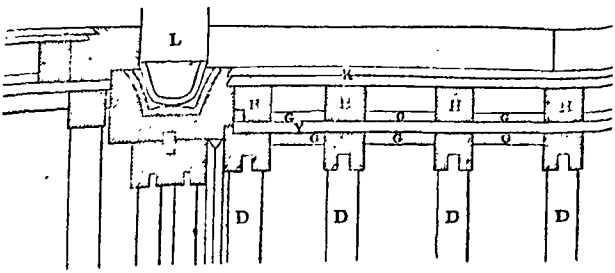


Fig. 2847. SECTION THROUGH PLATFORM.

D, Piles. G, Stone. H, Sleepers.
K, Planking. L, Heel-post. Y, Planking.

comprise the whole thickness of the masonry, and be very difficult to displace. When only large rubble stone can be obtained, the platform should be concave, like an inverted vault: if the lock is on a solid foundation, it will be only necessary to give it a thickness of 27½ inches to 3 feet 3 inches: when the ground is of a doubtful quality, it is better to make a wide platform of from 4 feet 3 inches to 5 feet 3 inches in thickness, on which the walls of the lock and platform are constructed: if the ground have no consistence, piling must be adopted.

Down stream there should be a guard platform as deep as is practicable, and as this part of the lock is most subject to injury, it must be made perfectly solid, for which purpose the plan of the masonry of the platform should be concave, tangential to the direction of the wing-walls, forming a species of arch with them as abutments. The last course should be cut in a double section, making a hollow arc above; the key-stones will then be perfectly closed, and, independently of the cramps, this course, which holds together all those of the platform, will be as solid as it is possible to make it.

The Projection of the pointed Sills. — M. Belidor has given dimensions for this part of a lock, but they are too small for general purposes. He remarks first, that if the gates form a right angle, the projection should be equal to half the opening, the greatest that could naturally be given them, and this angle would be the most advantageous for shutting the gates against each other, because the thrust of the water acting perpendicularly against them, each gate would push the other at right angles to the length of

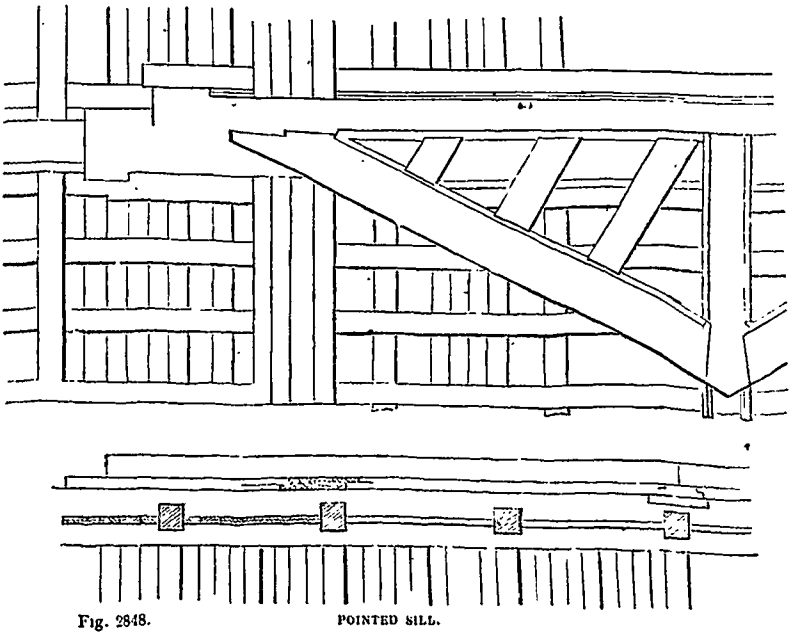


Fig. 2848. POINTED SILL.

the timber, in which direction they have the greatest strength; but, on the other hand, by giving them an obtuse angle, there is the advantage of having the leaves narrower, and consequently stronger. If this angle be extremely obtuse, that is to say, if the gates merely formed a straight line, they would certainly have the least width that could be given them, but they would not support themselves, a very essential defect; a mean should be adopted either between the pointed sill having the greatest projection and that which has the least, or between the greatest width of gate and the least, or between the greatest angle the gate forms with the lock and the least. In the first case the projection of the pointed sill would be a quarter of the width, in the second nearly the third, and in the third about the fifth. M. Belidor has determined upon the latter, but the angle is not sufficiently projecting, as it prevents the timbers from resting against each other, and giving it a greater projection, increases the width of the gates, the solidity of which may be maintained by additional strength; thus it appears a selection must be made between the other two methods, and possibly the most judicious would be a mean, that is to say, to give to the projection of the pointed sill between a third and a quarter of the width of the lock: either might be adopted without any inconvenience.

Pointed sills are sometimes made of timber, and frequently of stone; the latter is very

liable to chip, the joints wear away, and allow the water to pass through, which it is exceedingly difficult to prevent. These inconveniences may be in great measure avoided by placing in front of the stone sills two pieces of timber, to receive the gates when closed, which can be much more easily cut than the stone, and consequently the gates, &c., be made to fit exactly; by bolting the pieces of timber to the stones beneath them, and securing them in the wall, and filling the joints with moss, all filtration between the timber and the stone may be effectually stopped.

In locks of rivers whose course is over stones or gravel, there is considerable inconvenience with regard to the pointed sills, pebbles often lodging between them and the gates, preventing their close shutting, and causing a loss of water, which it is very difficult entirely to prevent, but which is in some degree obviated by a space of a few inches being left between the gate and the bottom of the platform; the sill and the lower rail might also be chamfered, so that the gate in shutting should drive the pebbles before it. Sluices to gates are about 25½ inches square, and are raised above the lower rail of the frame, so that the water which comes out makes over the gate down stream a fall over the platform, which wears away, and in the course of time materially injures it. It would therefore be more advantageous to make the water flow out under the gates, and throughout their whole width: there would then be only a film, which acting horizontally would be less injurious than when flowing in a direction inclined to the horizon.

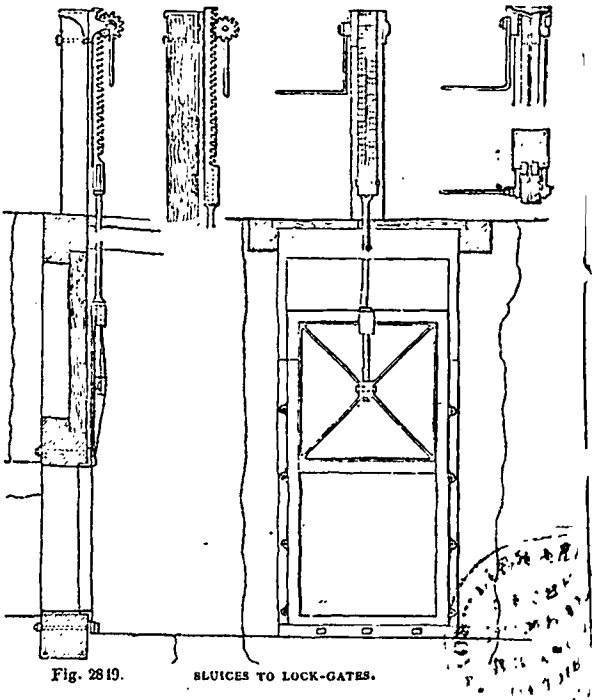


Fig. 2849. SLUICES TO LOCK-GATES.

The lower rail should also be placed at 12½ inches above the bottom of the posts; the sluice should only be a simple plank, equal in length to the entire width of the gates, with its ends attached to two small posts raised by means of a lever. The pointed sill, against which this rests, should have but little height, and the bottom of this sluice-board should be cut in a bevel form, to throw off the stones and gravel that might be driven towards the sill, which it is sufficient to make more elevated in the centre to receive the chamfered or bevelled planks forming the sluice.

This construction has another great advantage, that of producing a current under the gates, carrying away whatever might stop there, and is particularly calculated for river gates.

It is generally admitted that the portion of the platform where the gates move should not be in an inverted arch, but extremely solid, and so constructed that the water cannot filtrate through or flow out at the platform between the discharging shoulders: if attached to the pointed sill, which must be always on a level, the form of an inverted arch may be given to it.

The Gates of Locks are composed of two posts placed vertically, and several horizontal rails; the

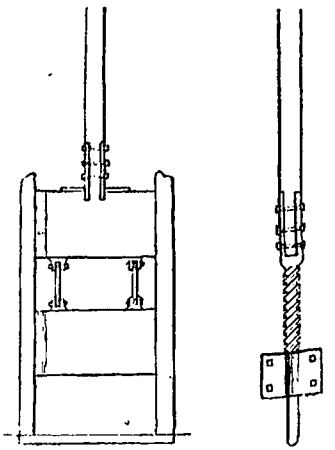


Fig. 2850. DOUBLE VALVE FOR TIDE.

former, being supported throughout their height, are not subject to much wear, although they are of larger scantling than the other timbers of the gate, which is necessary, as they sustain the entire framework: the horizontal rails resist the weight, and as that weight is greater where the rails are placed below the level of the water, it would seem natural that their dimensions should vary in proportion to the weight. To determine these dimensions it must be recollected that the thrust of water against vertical surfaces is equal to the weight of a prism of water having its surfaces as a base, and its height half that of the water. It must next be considered that the rails of the gate are at least 26 inches apart, and 38 inches from centre to centre, so that, on account of the casing of plank in the first instance, 12 inches of height support 26 inches of water, and in the second 38 inches. The weight supported by each rail will be found by multiplying their length, the interval from one to the other, the height of the water above the centre of the rail, and the whole by 62 pounds, the weight of a cube foot of water; the product of these measures will be the number of pounds which the rails ought to support throughout their whole length.

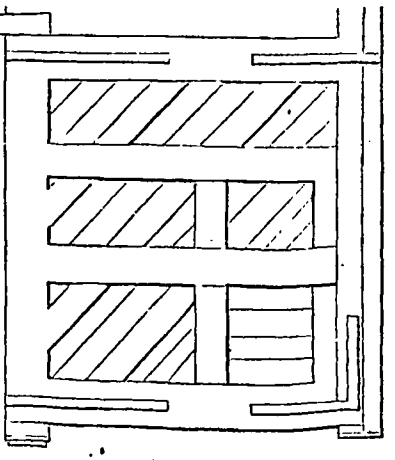


Fig. 2851.

Timbers from 4 to 5 inches square would be sufficient for small gates, and for larger from 8 feet 6 inches to 10 feet 6 inches of fall, with a width of 17 feet between the hanging-posts, the rails would be sufficiently strong if from 7 to 8 inches square, putting six rails in the height. They are generally from 9 to 10 inches at least, which is double the strength required; it is true that the gates are more durable, but the weight is greater, which is sometimes injurious to the collar and the masonry to which it is attached, requiring more reparations than lighter gates.

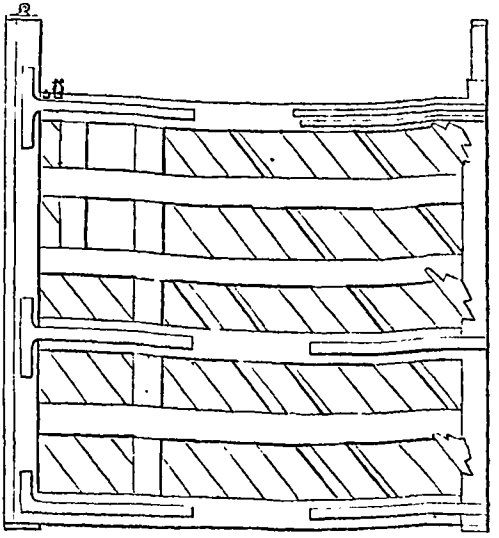


Fig. 2852.

The frames or styles of gates should be at least 5 inches in thickness more than the rails, and the joint covered by a fillet, as well as the edge of the planks, which are affixed perpendicularly to the rails, and mortised into the styles, increasing the strength of the rails and the framework by their greater thickness. Braces are also introduced between the rails, which aid materially in strengthening them, and by their inclined position transfer the stress to the hanging-post.

Great gates should always have a line of braces placed diagonally, and making an angle with the lower rail; all the braces above should have the same effect, and consequently the same inclination: those below resting on the lower rail tend to depress it, and, even when properly framed and pinned into the rails, their inclination towards the hanging-post renders them insufficient to sustain the lower rail; but they may be made useful by giving them an inclination in a contrary direction, and uniting them by pins to the rails, producing the effect of a St. Andrew's cross, without which no framework of carpentry is perfectly solid.

Instead of inclining the braces below the diagonals on the side of the strutting-post, a bar of iron is sometimes placed diagonally from the collar to the lower end of the strutting-post, which is an excellent contrivance; or the planks may be placed diagonally, inclining them

from the side of the hanging-post, and crossing them solidly, especially that of the diagonal above the hanging-post, and at the extremity of the lower cross-piece; or instead of a plank, a piece may be let in in an opposite direction to the cross-pieces, which must not be mortised into, or very little, that it may not be in any way weakened; this piece united carefully to the lower cross-piece would tie it to the post, and give more solidity to the framework; the diagonal position of the planks gives them more strength to resist the pressure: there is a little loss of material, but, on the other hand, plank of different kinds may be used after cutting out the knotty or defective portions.

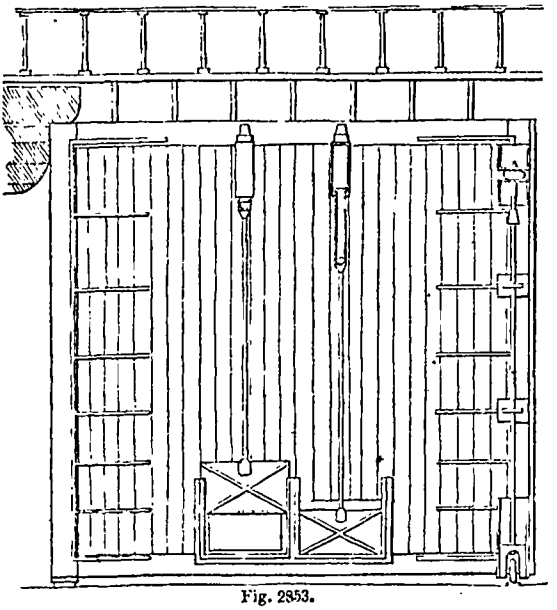


Fig. 2853.

Gates are opened by means of large timbers fixed above the posts, forming a counterpoise to the gate, and preventing it from grinding the collars and racking the framework; for this purpose the tail of the balance-beam must be very large: trees are sometimes used with their butt ends not cut off, to which it is easy to add any additional weight; this balance-beam should be united to the upper rail by a St. Andrew's cross, which serves also to maintain the entire framework. The hanging-posts often allow much water to be lost, in consequence of being obliged to give them sufficient play, and this could scarcely be prevented if the pivot had not a little motion, and the collar fitted exactly; but the weight of water occasions the gate to unite by pressing it considerably against the hanging-post; still as this is cut circularly, it only leans against a small portion of its surface, and the water easily passes, notwithstanding the great pressure. To remedy these defects, the posts should be partly cut in a circular form, and partly bevelled; the latter leaning along its whole length upon the rebate made to receive it, which having a corresponding bevel interrupts any filtration; the circular part should not touch the masonry, but have

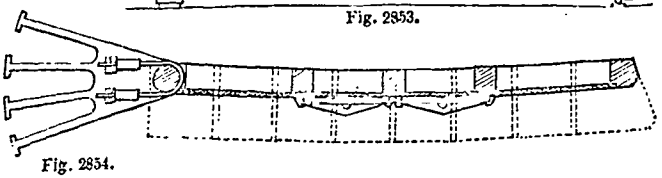


Fig. 2854.

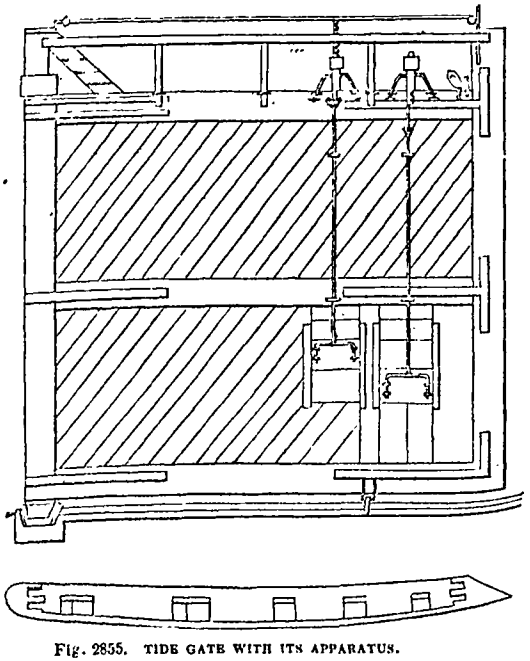
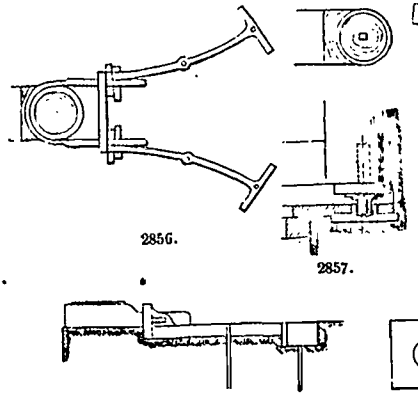


Fig. 2855. TIDE GATE WITH ITS APPARATUS.

sufficient play without affecting the ease of the motion; it is also advisable to attach pieces of timber to the hanging-posts, which may be bolted and cramped to the masonry, and by caulking the joints the water is prevented from passing between them and the



2856.

2857.

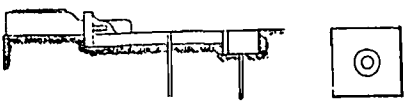


Fig. 2858.

2859.

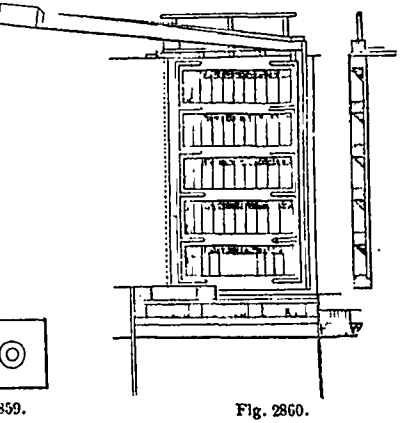


Fig. 2860.

masonry. The strutting-posts also allow a considerable quantity of water to escape, because, if not very exactly fitted, they only touch on one of their edges, and consequently it is scarcely possible but that the water should find a passage: to make them touch throughout their whole length, they should be cut in a circular form, one concave and the other convex, so that if the gates had even a play of some inches, they would always touch very nicely; the curvature of the posts should form part of a great circle of from 10 to 13 feet radius.

The gates of locks of navigable canals are generally made in a right line, but in great sea-locks they are curved: Belidor has demonstrated, that these latter are not more solid than the former, but this must only be understood when the curved timbers are made out of straight pieces; for it is undoubted that, if naturally curved, they are much stronger, and will resist more pressure than straight pieces, especially when resting on their two extremities. The collars embrace the whole heel-post, which being generally 12½ inches in diameter produces considerable friction, especially when the balance-beam does not act as a counterpoise: a large bolt may be placed in the axis of the post, and a smaller collar be substituted to confine it; but this method can only be applied to chamfered posts; round posts must have a motion in their collar to lean against the hanging-posts, which could not be effected by an axis; the collars must be attached to iron anchors strongly bedded into massive masonry. The pivots often get deranged, the posts, as generally made, causing considerable play; if these were bevelled, the pivots might be fixed and bedded in large stones cramped to those adjoining, or united with anchors to the surrounding masonry. Formerly the pivots were made of copper, but cast-iron is equally efficient; they should be the same size as the ends of the posts, and terminated at the lower end in a spherical form. The other iron work of the gates consists of squares laid on at right angles, which must be very strong; it is also well to lay on the rails of each sluice a band or two of iron to bolt them securely together.

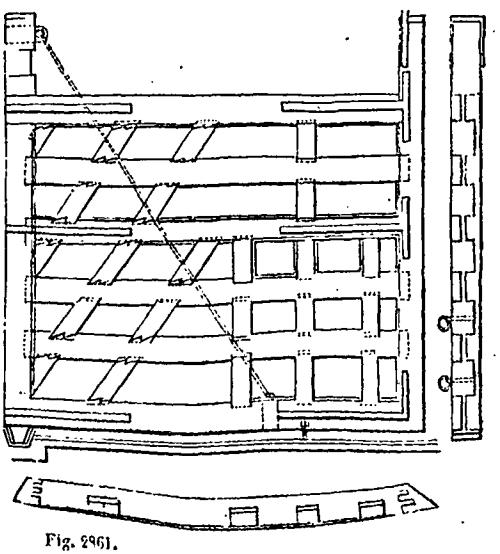


Fig. 2861.

Lock Gates measuring 8 feet from the centre of one heel-post to that of the other are in some canals on a segment of a circle, the chord of which is about the

sixth of the span, or a little more: these proportions not only allow of the gates being smaller, lighter, and stronger, but also increase the pressure of the heel-post against the hollow quoins, which renders them quite water-tight. Where canals are narrow, the paddles of both the upper and lower gates are usually kept open by an iron pin inserted between the teeth of a rack and pinion which raises them: when the paddle is required to be shut, the pin is withdrawn, and the paddle falls by its own weight.

Hollow Quoins, or upright circular grooves, are formed in the side walls, at the ends of the timber sills, serving as the hinge for the gates; the upright post that turns within them is called the heel of the gate, and the other the head. The former are retained in their position by a gudgeon or pivot turning in a cup let into the foundation stones for the purpose; sometimes the pivot is fixed, and the cup revolves upon it. The upper part of the post is retained by an iron ring or strap let into the side wall, and made very secure; the hollow quoins should be worked with great attention; they are usually of stone or brick, though cast-iron has been found well suited for the purpose.

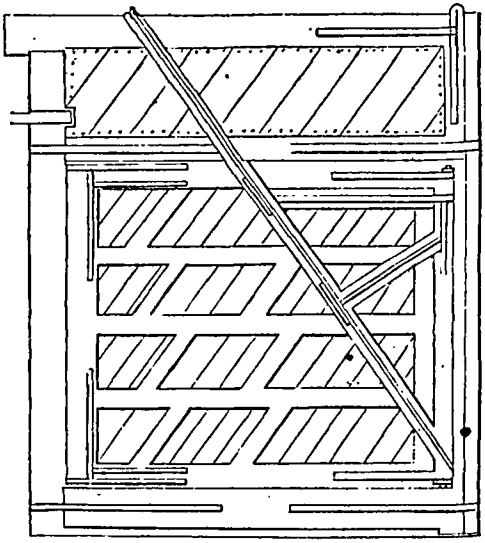


Fig. 2862. FRESHWATER LOCK.

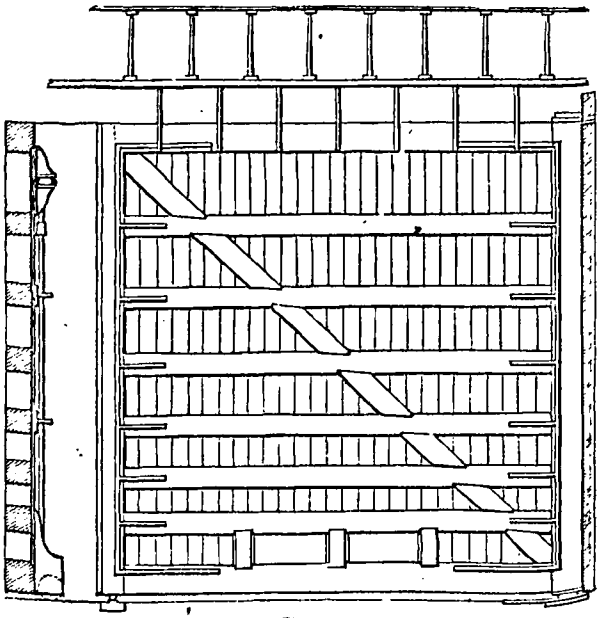


Fig. 2863.

Lock Gates of large Dimensions are now usually opened and shut by machinery, and the boom or spar attached to the head-post entirely dispensed with: on many canals a rack-bar of wrought-iron is connected with the gates, which are furnished with rollers to run in a groove fitted into the sill, and by working a wheel and pinion, they can be opened and shut at pleasure. We ought not to omit mention of several gates formed like boats, upon the principle of the camel, which rise and fall in deep recesses prepared to receive them as water is pumped out or admitted into them: such boat-gates are sometimes constructed with three parallel keels, which fit into as many grooves in the side walls of the lock; they are maintained in their position by admitting the water, and raised by pumping out their contents, after which they are floated away; for the stop-gates of docks such a contrivance is well adapted, but where the navigation is regular, as on a canal, they are not found to answer, from the time requisite to open and replace them.

The Boom or Spar attached to the head-posts is brought over a windlass, placed on the lock walls a little above the gate; a rope is made fast to the end of the spar, and by two or

three turns on the windlass, the gate is either open or shut; a rack bar is occasionally employed for the same purpose. When the gates are very heavy, a roller or truck wheel is placed under the foot of the head-post, and made to run in a quadrant groove, which assists the motion.

The Angle to be given to Double Lock Gates has long occupied the attention of engineers, and the view now taken of the subject may be thus defined:—the pressure of the water on one of the gates, which we will call B C, is in proportion to its breadth: the strength of the gate being inversely as its breadth, the effect of the pressure upon it is as the square of B C. The support afforded by one gate to the other, which we will designate as C A, is as a perpendicular raised at the end of a line B C at E, represented by A E: the strength of the gate is therefore as A E directly and inversely as BC^2; but A E is the sine of A B C; the radius A B — B C is the secant of the same angle to half the radius B D. The strength of the gate is therefore,

$$\frac{AE}{BC^2} = \frac{2 \sin. ABC}{\sec.^2 \frac{ABC}{2}}$$

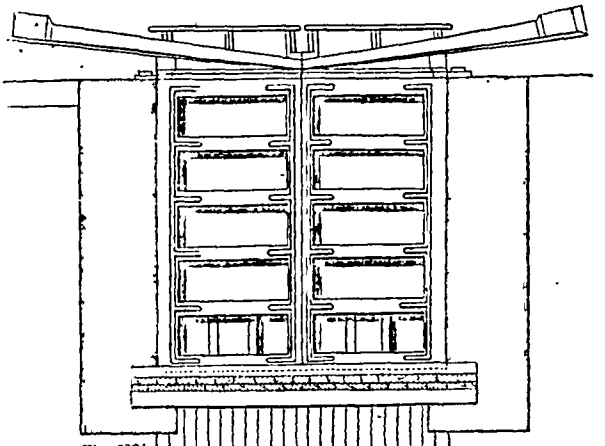


Fig. 2864.

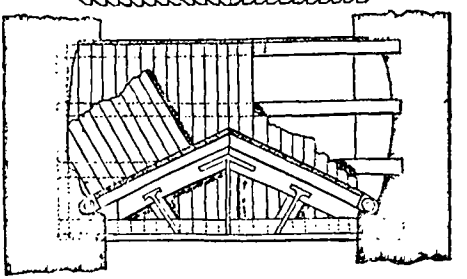


Fig. 2865. PLAN AND ELEVATION OF DOUBLE LOCK-GATES.

or, as the cosine is the reciprocal of the secant, as sin. × $\cos.^2$ of A B C, the angle at the base. The maximum value of this expression is when the tangent of A B C = $\sqrt{\frac{1}{2}}$, or = 0·7071,

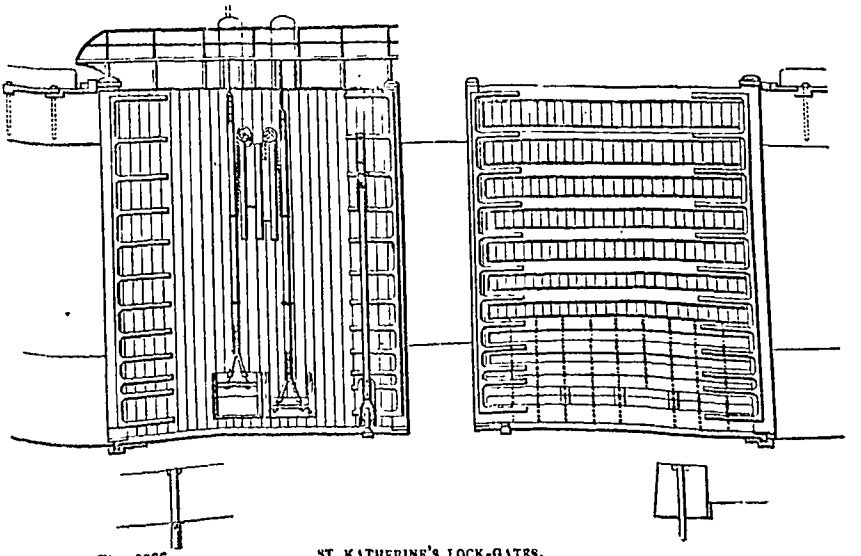


Fig. 2866. ST. KATHERINE'S LOCK-GATES.

or when the angle at the base is 35° 16′ nearly, and the sally of the gate is $\frac{1}{20}$, or a trifle more than one-third of the breadth of the lock.

The Gates of large Locks, or those at the entrances of docks, as at St. Katherine's in the port of London, are framed with whole timbers, the uprights and horizontal rails being secured to each other by strong wrought-iron straps. The planking which covers the face of the framework is placed perpendicularly, and the paddles are worked by a rack and pinion. The turning or heel-posts are held in their position by iron ties let into the stone-work.

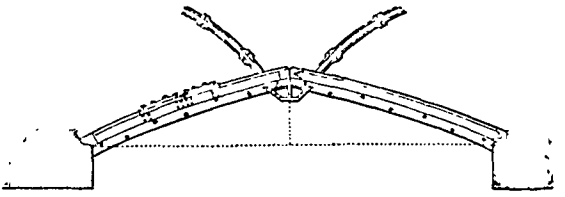


Fig. 2867. PLAN OF GATES.

Some lock-gates have their paddles made to open and shut by the movement of a lever, the lower end of which being loaded keeps it always over the aperture in the lower part of the gate: when it is required to be moved, the upper part or handle of the lever is pulled back, and the water forcing its passage through, keeps it open until its weight overcomes the power, and it is balanced back into its original position.

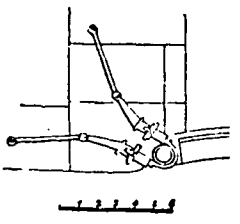


Fig. 2868. HEEL-POST.

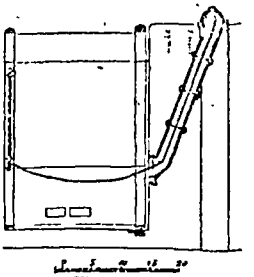


Fig. 2869. SECTION.

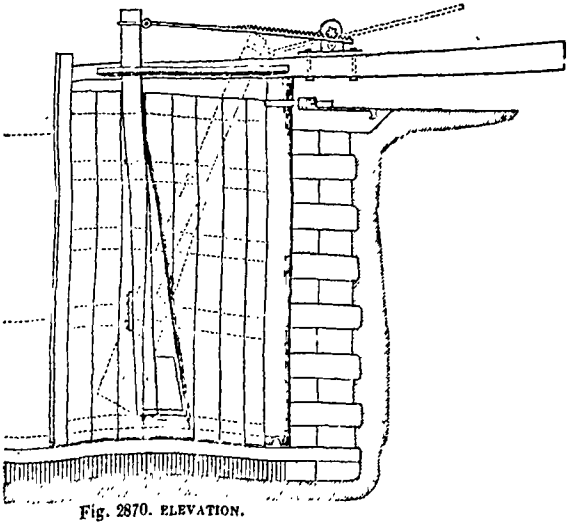


Fig. 2870. ELEVATION.

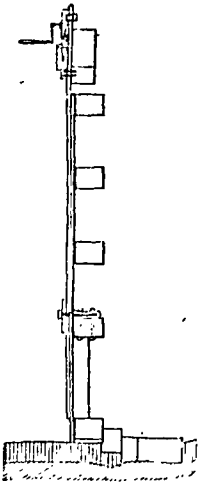


Fig. 2871. SECTION.

The crank and pinion working in a toothed rack are now generally applied to raise the paddle.

Screws are sometimes used for this purpose, formed of wood, sliding up and down in a rebated frame, fixed in the stone mouth of the conduit or paddle-hole; the lateral pressure of the water, occasions it to adhere closely to the frame, so that it is not only necessary to make it run with the grain of the wood, but also to have considerable power to move it; this is occasionally effected by means of a long iron lever, with an eye at one end that spans the square end of the screw and allows a sufficient force to be applied to raise the paddle.

There are several applications of the screw, one of which, as used at the gates of Dunkirk, is very simple, and was for a long time adopted throughout Europe. To overcome the hydrostatic pressure and friction, at the mouth of the paddle-hole was a horizontal circular opening, within which was inserted an open cylinder of wood or iron ground to fit it, which could be

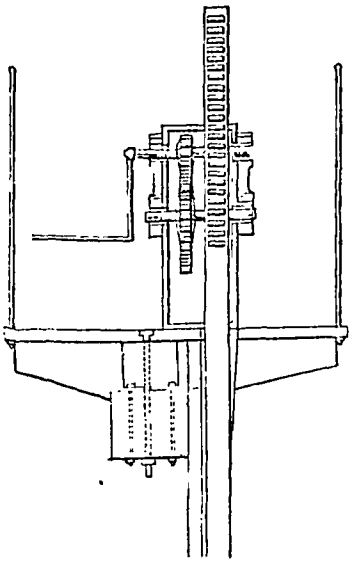


Fig. 2872

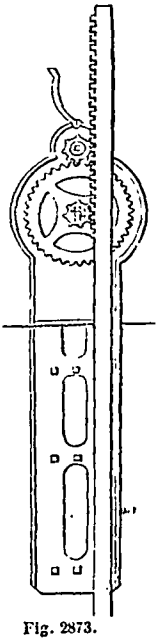


Fig. 2873.

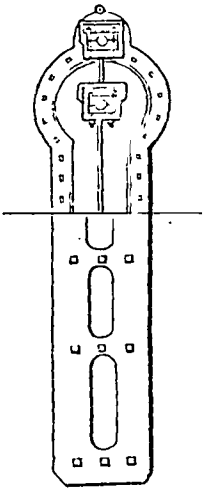


Fig. 2874.

raised by a lever; the waste water of the canal could then escape over the upper lip of the cylinder, and afterwards pass out by the paddle-holes, in the same manner as the waste water of a cistern.

At the Caledonian Canal the head and heel-posts of the gates are connected by cross rails, and well secured by iron straps. The weight of the capstan-head employed to open

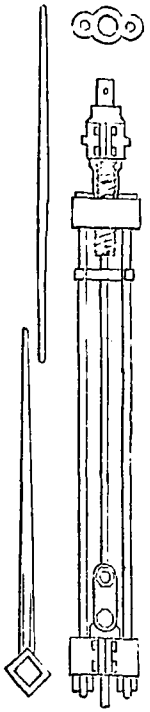


Fig. 2875. DUNKIRK.

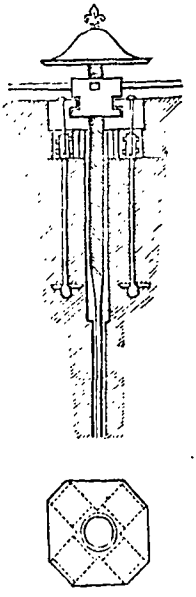
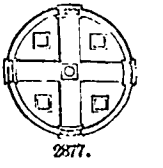
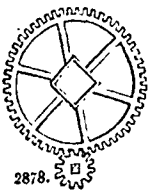


Fig. 2876.



2877.



2878.

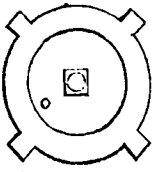


Fig. 2879.

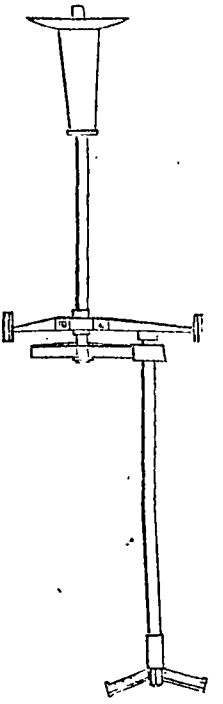


Fig. 2880.

them is 2 cwt. 1 qr. 14 lbs. and that of the wheel and pinion, 3 cwt. 0 qrs. 26 lbs. ; the bottom ring is shown in the lower figure, with its footsteps or gudgeon, round which it works.

The capstan works the chains, which lead to the middle of the head-post on either side, and is admirably well adapted for its purpose.

The covering plate of the capstan-hole is made very solid, and prevented from turning round by six projections on its outer edge.

The bridge and conical roller which turn the capstan is also of iron, the weight of the former being 2 cwt. 6 lbs.

The pivot working in a recess is sometimes so arranged that the cup which receives it is let into the stone sill, and prevented from turning by two

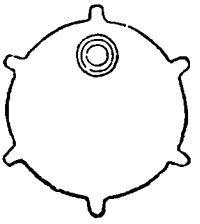
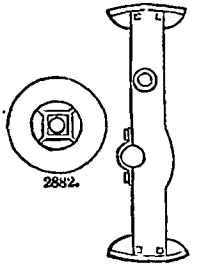


Fig. 2881.



2882. 2883.

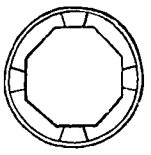


Fig. 2884 PIVOT.

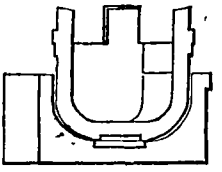


Fig. 2885. PROFILE.

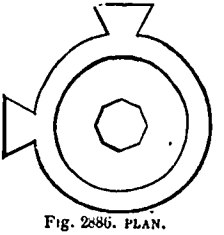


Fig. 2886. PLAN.

dovetail pieces at the sides; to attach the pivot to the turning-post, four vertical projections or dovetails are placed at equal distances round its upper edge, as shown in the figure. -

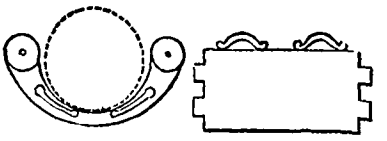


Fig. 2887.

The collars to the turning-posts are usually of iron, the interior radius of which is shown by the dotted line, and its elevation at the side. The iron rollers under the other post of the gate, which runs on an iron plate, are so fixed that they clear themselves in the grooves cut to receive them; they are usually from 5 to 6 inches in diameter, and run on an iron axle fixed into a frame that receives the end of the gate. Where the wheels run upon timbers, the sill is formed of several pieces, altogether 4 inches in width: the radius of the gates determines their curve, and they are secured by iron cramps to the ground timbers or stone sills. Around the heel-posts of some gates is a collar, to which a rod of iron is attached that passes through the entire width of the lock-walls, where it is secured in blocks of masonry, or by forming an eye it may be linked on to another joint, and made fast to an upright post.

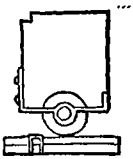


Fig. 2888.

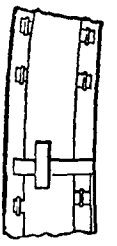


Fig. 2889.

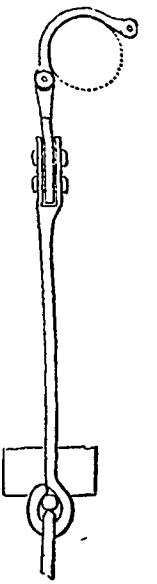


Fig. 2890.

In attaching the iron-work to lock-gates we must be cautious not to weaken the framing, or in any way to obstruct their motion; for as they are of course very heavy, and the lower rails nearly in contact with the bottom or floor of the lock, should they lose their form, the mitre posts by sinking would impede their opening and shutting: as the gates are sometimes covered by water and at others left dry, the material of which they are formed should be carefully selected, and all the metal work applied to them protected from the effects of these alternate changes. To balance the gates and support them properly is the best method of preventing their tendency to sink and drag; and if every precaution is not taken to make them move easily and readily, they will be a constant trouble and expense, which can only be remedied by their total removal.

The capstan used at the basin of Dunkirk will give some idea of a simple arrangement for the purpose of hauling the boats from the reservoir into the stream of the canal: upon a platform of timber on the quay, an upright post is turned by handspikes, which coils the rope around it.

The profile of a capstan executed at Cherbourg shows a nut pierced to receive an iron rod 4 inches square, set 5 feet in the side of the dock-walls, where it is held firm by two long arms terminating in the form of a T; this arrangement is the most simple, and not so likely to decay as the timber framework. The upper portion of the lock or fore bay is the usual position for the capstan; the tail bay of locks sometimes also requires one where the canal communicates with the ocean.

Iron Lock Gates at the Wet Dock at Montrose.—The frames are of cast-iron, and entirely covered on both sides with wrought-iron boiler-plate: where they are placed the entrance is 55 feet wide in the clear, and the centre of the heel-post is 1 foot within the face of the wall, the distance between their centres being 57 feet: the height of the gates is 22 feet 6 inches; they point 10 feet, and their ribs have a curvature on the hollow side of 18 inches. The heel-posts are 21 inches in diameter, and in form a little more than a semicircle; after casting they were turned in a lathe: the thickness of the metal is 1¼ inch; they each fit into a cast-iron socket, and work on an iron gudgeon 10 inches in diameter, cast on a sole-plate 4 feet 6 inches long, 24 inches wide, and 2 inches thick; this is dovetailed and riveted firmly into the stone, and afterwards so keyed as to press the heel-posts into the quoins, which are of Kingoodie stone, polished as nearly to the circle as possible, and the stone and iron are in such close contact, that the water is effectually prevented from passing throughout any portion of their height.

The mitre posts are 18½ inches in breadth, 1½ inch thick: holes are cast in them for the introduction of the iron bars, of which there are eleven to each leaf, 2 inches thick,

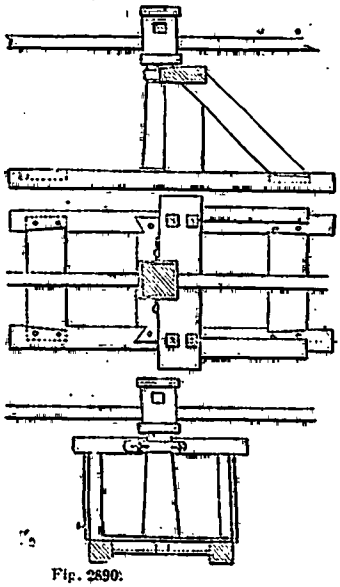


Fig. 2890.

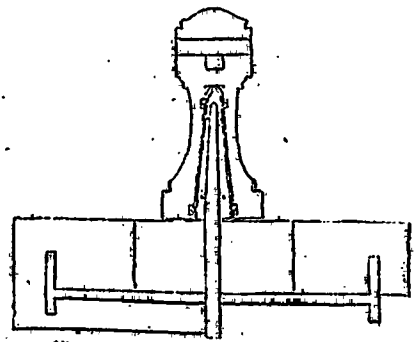


Fig. 2891. CAPSTAN.

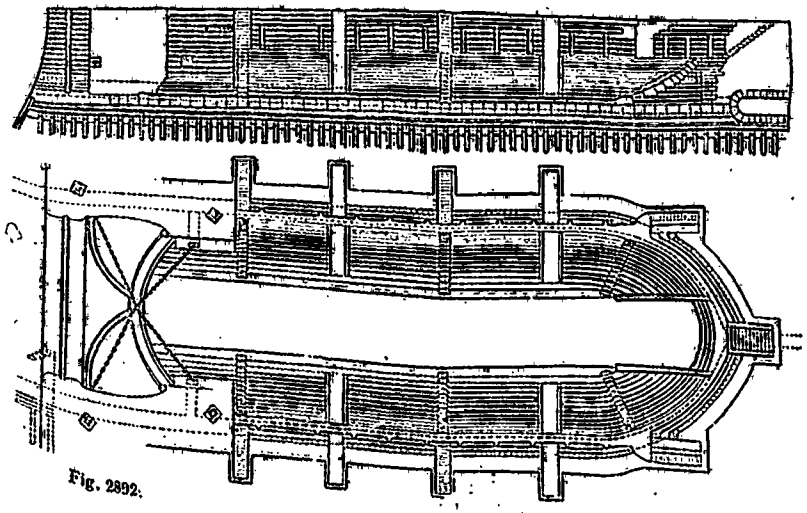


Fig. 2892.

16 inches broad at the ends, and 18 in the middle; their cross ends are 18 inches in height and 2 in thickness, with 4¼ inch screw-bolts to each, which pass through the heel and mitre posts. The clap sill was cast in two pieces for each leaf; it is 8 inches in depth and 1½ inch thick; the height of the sill above the platform is 15 inches. The bottom bar is of oak 12 inches thick, 17 inches broad at the ends, and 19 in the middle; this is bedded on felt to the lowermost cast-iron bar, and securely fixed by 1¼-inch bolts. The boiler plates which line both sides of the gates are so arranged that they break joint; for 6 feet in height their thickness is ⅜ of an inch, above only ⅝, they overlap each other about 2½ inches, and were riveted on while hot, that the rivets might completely fill up the holes. The collars of the heel-posts are of wrought-iron, 4 inches by 2 inches, keyed through the anchors, which are of cast-iron, 9½ inches square; they are dovetailed into the quoins, and run with lead. The roller segments or railways are 10 inches in breadth by 1¼ inch, 4 inches in thickness; they are sunk into the stone, and securely bolted, and bedded with felt and white lead.

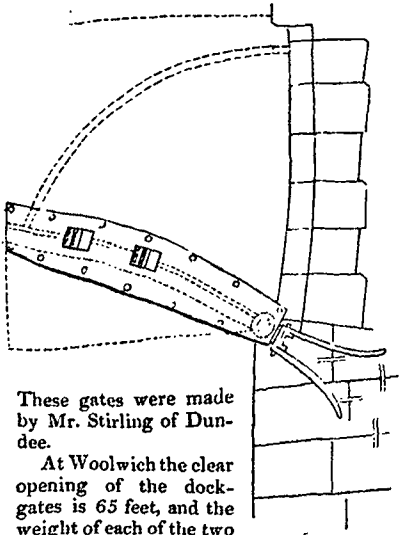
The rollers are of cast-iron and conical, 18 inches in diameter, and 5 inches in thickness, with turned steel axles; the roller boxes are of cast-iron, 1½ inch thick, moulded to the bevel of the gates, and fastened by screw-bolts through the flanks of the horizontal bars: cast-iron covers confine the roller blocks, which slide up and down withinside the boxes by the action of the top screws; the roller bars are of wrought-iron, 3 inches in diameter, keyed into the blocks at the bottom, each being stendied by three plummer blocks; each bar near the top has a coupling, with a square threaded screw, and a brass nut at the top, working in a cast-iron bracket, which bears the whole weight of the outer end of the gate, and is fastened by three screw-bolts through the flanges of the horizontal bars. Each leaf has a sluice, 3 feet by 2, the frames of which are 7 inches broad and 1¼ inch thick; the sluice valves are also 1½ inch thick; all the screwed bolts have zinc nuts, to prevent the iron from rusting: the sluice-rods are 2 inches in diameter, and have a square threaded screw, and a brass nut at the top; these are worked by a wheel and pinion, and bevelled gear, with a crank handle, nearly level with the hand-rail.

The gangway is 42 inches in width, and is supported on cast-iron brackets for each leaf; cast-iron ballusters and a wrought rail is attached to the convex side of the gates, with movable iron stanchions and chains on the other: in each heel-post is a pump with a brass chamber and boxes, 2½ inches in diameter, with a lead pipe down to the bottom.

The gates are worked by four double-purchase capstans, and gearing with seven 8-inch chains.

Their weight is as follows,—

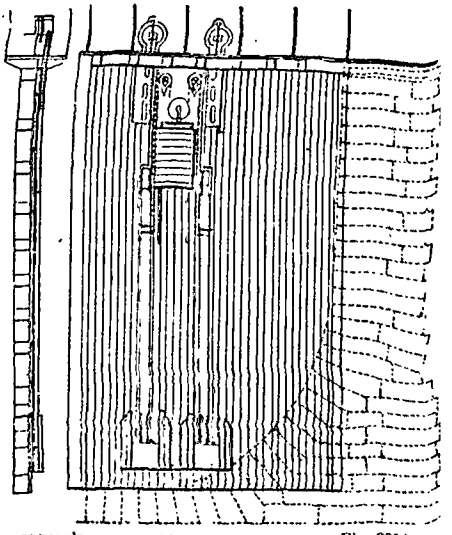
	Tons.	Cwt.
Cast-iron work in the gates - - - - -	64	14
Wrought-iron — - - - -	22	15½
Brass — - - - -	0	5
Zinc — - - - -	0	1½
Cast-iron in segments and other fittings - - -	19	0
	107	0



These gates were made by Mr. Stirling of Dundee.

At Woolwich the clear opening of the dock-gates is 65 feet, and the weight of each of the two iron gates is 150 tons.

Fig. 2893.



PRINCE'S DOCK, LIVERPOOL. Fig. 2894.

Inclined Planes and Lifts, mentioned by Mr. Smeaton as early as 1774, are adopted at many of our canals to raise and lower the boats from one level to another, and by some

engineers are deemed preferable to locks: in the neighbourhood of Taunton are examples of both systems, which, by the aid of machinery, enable the boats to pass from one canal to the other, from a height of above 80 feet. At the summit of the inclined planes is a steam-engine, of sufficient power to pull up a sledge, which receives the loaded boat; the chains pass over a cylinder of large diameter, but are frequently out of order, and sometimes break, to the destruction of the vessel to be hauled up.

The Lifts are more easily worked, as a single attendant can raise or lower a boat from one level to the other. There are two lock chambers, at the summit level of which, working in a lofty frame, are three or more large wheels; the outer circumference, or rather their radii, are exactly over the middle of each lock-chamber; around their periphery chains are suspended, and at the end of each is a fork or iron attached to the two sides of a sledge or boat, large enough to receive the one freighted, passing either up or down the canal. When a boat is to be raised, the sledge which receives it is at the bottom, and the other on a level with the upper water of the canal, which the attendant allows to run into it, and when the weight is sufficient, it descends in the lock-chamber, and in falling raises the other which contains the freight; the end of the sledge opens, and it is then admitted through a pair of gates into the upper channel: when it is required to descend, the sledge receives the boat, after that at the bottom has been filled with water; and when it has acquired nearly its balance by letting off a portion, it mounts and the loaded boat descends.

Means of making the Water enter and leave the Locks.— One of the greatest inconveniences, and causing great injury to locks, arises from the velocity with which the water from the upper interval rushes into the chamber, or from the chamber into the lower interval; the great difference in the level of the water and the space requisite for the opening, in order to avoid loss of time in filling or emptying a lock, causes a considerable rush of water, which, falling from the upper interval on to the platform nearly perpendicularly, seriously injures it, as does also another volume of water issuing from the lower gates, although its effort is nearly horizontal, and consequently less injurious: the weight is, however, more than double that of the upper part, the rapidity of the water and its consequent effect greater; false platforms are therefore constructed some distance below the locks, to protect the edges of the canal in this part, but, notwithstanding every precaution, frequent reparations are required. The gates being inclined towards each other cause the current through the sluices not to be parallel to the sides of the canal, and to strike the edges at a certain distance, whence they rebound from side to side, producing considerable damage. If the two sluices were opened at once with equal velocity, the two currents meeting with equal force, a mean current would be the result, taking the direction of the lock, but there is frequently only one lock-keeper to open the sluices, and if there are two, they do not act together; the current is therefore almost always directed to one side, especially when the sluices are first opened, at which time the rapidity is the greatest.

A great inconvenience arising from the rapidity of the water is modified by making it flow from the bottom of the platform in several smaller streams, which prevent its force from being more directed to one side than to the other. For this purpose, on the upper side under the lower pointing sill, and in the thickness of the wall which constitutes the fall of the lock, an arch is turned, having the top perforated by two holes 2 feet 2 inches in diameter; in the upper shoulder walls, behind the gates, are also two conical recesses, 3 feet 2 inches square, forming an entrance for the water, the bottoms being paved with a large stone pierced by a hole 2 feet 2 inches in diameter; these openings communicate by means of bent tubes worked into the masonry, either of cast-iron or stone; if of the latter material, semicircular gargoulles are cut, cramped together, and the joints united with moss and mastic; or they may be made of several flat stones properly cramped, forming a square trough, the joints being stuffed carefully, and the whole confined within a mass of well-executed masonry. The openings are closed with conical plugs of the shape of the holes in the stone, furnished with a handle acted upon by a lever on the platform of the lock, and by the action of which the water passes from the upper interval into the chamber: to close the pipe the plug is let fall, and a blow is given to the handle with a mallet; this method is more expeditious than racks or screws, and the most efficacious for closing an opening.

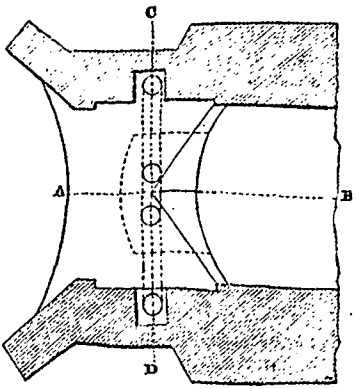


Fig. 2895. LOCK CHAMBER.

The water passes from the chamber of the lock into the lower interval by a nearly similar arrangement in the platform behind the gates, and

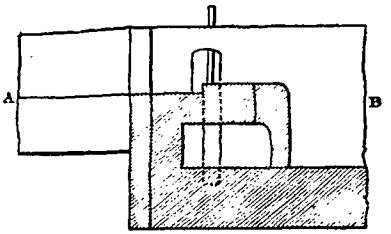


Fig. 2896. SECTION AT A B.

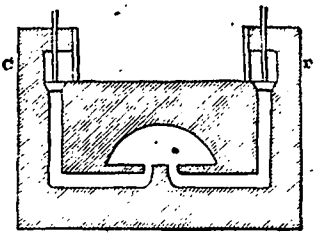


Fig. 2897. SECTION AT C D.

in the middle of the shoulder walls for its issue: perhaps there would be a greater advantage in making the tube in the side walls of the chamber, above and below, the recesses of issue being higher than under the wall of fall: there is no fear that the striking of the water against the lower part of the wall of fall will in any way injure it.

In the pipes through which the water issues it rushes violently, but does not rise very high, as its expenditure at the mouth is greater than the quantity which enters at the same moment, and it may be rendered less rapid by making the tube larger at its exit than at its entrance. The recesses at the exit should be much larger than those of its entrance, and should be formed of large stones well cramped together, so as not to be easily deranged; the platform should also be well cramped, as well as the stones of the arch under the wall, and the wall at the bottom of this recess should be tied in with that of the upper guard platform.

Bridges and Towing-paths.— The former may be made either above or below the lock-gates; by placing them above, on the shoulder walls, the whole lock is free; and if the boats are loaded high, they meet with no impediment, but in this case, the balance beams must be dispensed with, but if the collars are well fitted, the gates will manœuvre sufficiently well; the shoulder walls must also be of an additional length, which increases the expense. By placing the bridges over the gates, and on the upper parts when opened, the expense is diminished; and as the load of the boats is seldom placed at the ends, which are left free for working them, this cannot in any way affect their passage; the only objection is that the lock-keeper has to pass over the roadway to shut or open the lower gates, which is, however, avoided by making a small vaulted passage behind or under the abutments of the bridge.

The Towing-path may be made at the side of the lock in two ways, one by commencing the ramp after the lower shoulder walls, in order to have a great platform at the side of the lock, and the other by making this ramp along the lock itself. The first method has the best effect, but is objectionable, as the height of the wall of fall requires the talus to be very steep, and covered with masonry. The second method is the most convenient; the banks of the canal being always at the same height, there is great economy in the excavation as well as in the masonry; the towing-path in both cases forms a right line, but the platform of the lock is not so wide in the second as in the first.

Stop-gates and Lets-off. — Between Corpach and Loch Lochy, at Sirone, on the Caledonian Canal, is an outfall of three sluices, which prevents any injury occurring to the canal banks from accidental breaches; they are in such a position at the end of the embankment that the water in the canal can be discharged when required for the purpose of repair. The open fan or trough is 80 feet at the widest end; that of the channel 18 feet, and the diameter of the semicircular pool about 82 feet: the three sluices shown in the elevation are each in width 4 feet, and in height 3 feet; their sills are on a level with the bottom of the canal, and the water falls 9 feet before reaching the bed

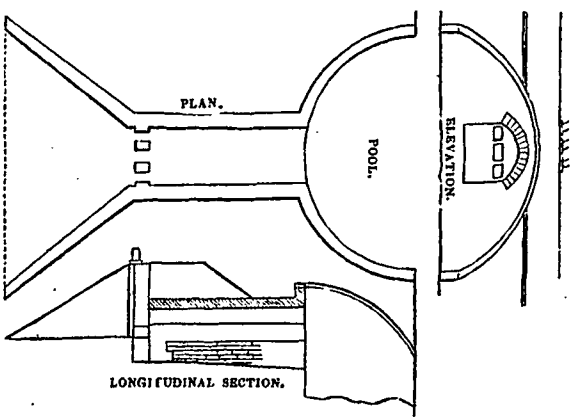


Fig. 2898. SLUICE AT SIRONE.

of the pool that receives it; the frames and sluice-doors are of iron; the latter are worked by rack and pinion-wheels within a copper groove.

In forming the channels for these lets-off, it is necessary to guard against the tearing up of the beds by the rush of water, by conducting it over a watercourse lined with

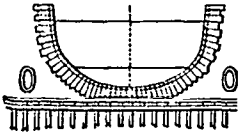


Fig. 2899.

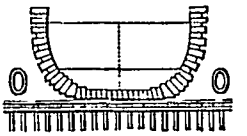


Fig. 2900.

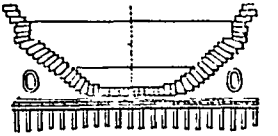


Fig. 2901.

masonry: a platform of timber is laid on piles over soft ground to receive stone; the section given to it varies according to the nature of the situation, or quantity of water to be discharged.

Stop Gates are sometimes placed at the bottom of the canal, lying partially afloat, so that any motion in the canal water makes them rise and shut against a vertical frame in the masonry of the abutments on each side: others are so contrived that they can be drawn across the canal from a recess, and so made to run in a groove, but the most simple method is the common lock-gate, or the sluices made in the sides of the canal, connected with drains as first described.

Reservoirs for supplying the Canal with Water must be placed sufficiently low to collect all the flood waters that may be required, and at the same time high enough to enable all the water they contain to be drawn into the summit of the canal: the basin should be made narrower towards its lower extremity, in order to contract the base of the embankment as much as possible, and the bottom and sides must be impervious to water. The dimensions of the embankment depend upon its height and the materials to be used; in general, the top is 3 or 4 yards higher than that of the water when the reservoir is full, and the breadth of the top is then about 5 yards; the outside slopes at the rate of three horizontal to one perpendicular, and the inside two to one. It is not only highly important for the engineer to take into consideration the best position for the reservoir, but also to be assured that he has the means of a regular as well as abundant supply of water on all occasions.

Aqueducts are of course requisite where rivers are to be crossed, as are weirs where the waste water is to be discharged; several of these have already been described in the history of canals.

CHAP. XXVIII.

DRAINING AND EMBANKING.

WHEN a level is to be drained, or the water carried off from the surface of a swamp or fenny district, the first point for the engineer to ascertain is the situation of the lowest outfall, in discovering which nature frequently affords him considerable assistance: the runs of water in flood times may be noticed, as well as the direction in which the several aquatic plants lie, these always pointing down the stream, and inclining with the currents, and when the flood waters are draining off, their motion and progress may be accurately measured. After the surfaces have been levelled, and the most available outlet decided upon, a main drain should be set out, from which oblique branches should be cut, pointing in the direction of the current; into these all the minor cuts and ditches are to be collected, so that, by intersecting the whole watery waste in an equal and regular manner, it may be effectually drained. The fall should be greatest at the most remote part, diminishing as the quantity of water increases; large and deep rivers run sufficiently fast when the fall is one foot per mile; for smaller rivers double that is requisite; ditches and ordinary drains require 8 feet per mile.

When water is drained from the surface, it should be made to pass away gradually, so that the sides and bottoms of the drains are not injured by friction: it should be in constant motion, that the channel may be kept clear and increase in velocity as it proceeds. When the surface is a dead level, the fall must be obtained by cutting the drain at the lower end deep enough to obtain one, which is always preferable to increasing the width; if there be a large body of water, less fall is needed, for, as above observed, the small drain requires a fall eight times as great as that of a large river, and the water flows over straight and smooth beds with greater rapidity than when the channel winds and rocks and shallows intervene to obstruct it.

After the quantity of water has been ascertained by meteorological and other surveys, the proportions and dimensions of all the drains must be considered, and care must be taken that their sectional areas and velocities are rightly calculated, so that the main drain which, like a great artery, is to receive them all, should not be overcharged, or in danger of overflowing. To facilitate the current, the slope of the sides of the drains or water-courses should have one and a quarter of base to one of perpendicular height, and their breadth at the bottom should be equal to two-thirds the depth of the water they contain.

When drains are cut through bogs, they may have a greater slope than when loose sand or gravel is to be operated upon, the fibres of the plants that constitute the peat or bog resisting considerably the action of running water.

When rivers which pass through low grounds are to be embanked or confined, that the floods they bring down may not inundate the adjoining lands, care must be taken to make the banks sufficiently strong, as the force increasing as the embankment is raised, in consequence of the stream not being able to expand itself in proportion to the increase of water, the more it is allowed to spread, the less occasion is there for strong barriers. The slope of such embankments should not be less than twice their height, and three times is necessary when the rivers they confine are affected by the tide, or subject to the force of the sea wave: the thickness at top should not be less than 5 or 6 feet, and the inside slope should be one perpendicular to one of base: for sea-banks, where the waves do not rise higher than 4 feet, the thickness at the top may be 6 feet, the slope on the land side 1½ feet for every 1 foot in height, and on the sea-side 4 feet to 1 foot in height. The slope on the land side must vary with the height of the waves, and should be increased to two and a half base to one of perpendicular height: the slope on the water side should be still more in proportion to the rise of the tide; for every increase of a foot in height the slope must be greater, so that when the waves mount to 10 feet in height on the water-side, it should be 10 feet for every foot in height.

When the earth with which the embankments are formed is of a gravelly or loose nature, it is requisite to carry up in the middle a wall of clay, or some impervious material; the system of puddling is now generally adopted, by which the percolation of the waters is prevented: there are several methods of protecting the face of banks towards the sea; in some parts of Holland, straw is used for this purpose, twisted first into ropes about 2 inches in diameter, and then laid on the face of the bank, and pinned down with hooked sticks, the whole surface of the dyke being covered with a regular mat of straw; in the course of time vegetation commences under it, blades of grass make way through the straw ropes, and the whole becomes a compact mass.

On the banks of the Thames and other large rivers, piling is generally adopted, which is expensive, maintains the soil very imperfectly, and is far from durable or holding: rows of piles are driven parallel to the river at 2 or 3 feet apart, raking with the slope of the bank, one standing in its retreat from the water higher than the other; these are secured by either working rods or wattling twigs between them, or by spiking horizontal pieces to them: the spaces between the rows are filled with chalk or stone, and brought as nearly as possible to a regular slope; this is called breach piling, and is now nearly abandoned. Kentish rag or other hard stone is infinitely preferable, and less costly, for maintaining a wall subject to the action of a river on which steam-boats are constantly passing; this, laid with a gentle slope from a little below the level of the lowest state of the tide, up to the summit of the wall, and the interstices run with fine gravel, has been proved to answer admirably well. The sea walls at Dimchurch and elsewhere, which have a slope of one in thirty or more, appear to have little or no disarrangement throughout any part of them: fascines and brushwood are used where expense is a matter of consideration, and when laid in the direction of the force, and pegged down with living willows, succeed well; but with materials of this kind the slope should be brought to one regular inclined line, and turfed over as far as possible; where a sea-wall is formed of sand, the interior is puddled with clay, and along with the sand Spanish broom or twigs of trees are strewed in layers, which bind the whole together. Within these walls provision must always be made to let off the land waters, and as the marshes bordering on the Thames and other great tidal rivers are considerably lower than the level of high water, it is important that the openings for their discharge should resist the entry of the water when at its highest state. The simplest form is a clapper or valve hung at the top, and falling over the opening of the pipe or trunk of discharge, which is kept closed, as the tidal water rises and presses against it.

Sluices are at other times used, which slide up and down in a frame, and the ordinary lock-gate either made to revolve on a pivot or to shut like folding-doors against a fixed frame. The passage through the wall consists of either a mass of masonry or a pipe of cast-iron; for culverts the latter is generally preferred.

When the passage of the fresh water is over a low beach or sandy flat, it is necessary to

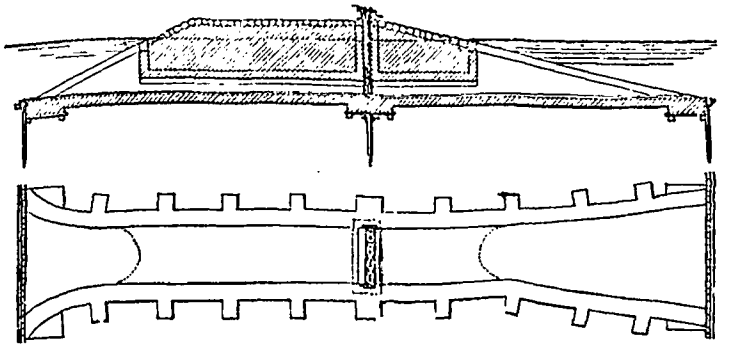


Fig. 2902. HARTLEPOOL.

protect its course by building jetties, or so effectually to cover it that no obstructions can occur.

After the main drain in a level has been cut, the rivers which run into it are embanked, and catch-water drains are formed to collect the water flowing from a higher level; the several channels must be kept open by dredging, scouring, and cutting down the aquatic plants and weeds. Attention must then be turned to the subsoil draining, that the surface may be rendered valuable for the purposes of agriculture.

Subsoil Draining. — Geology has assisted this operation very materially by rendering us acquainted with the quality and nature, as well as succession of the soils beneath the surface to be drained. The soils which are impervious are usually the most heavy, and the porous are those of a lighter quality. Clays, when they receive water, will only part with it by evaporation when left in a natural state, and therefore to make such a surface fit for agriculture, or to render it dry for any useful purpose, or to improve the atmosphere above it, requires considerable ingenuity and a great expenditure.

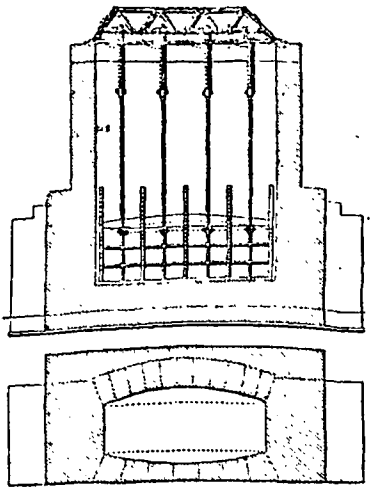


Fig. 2903. HARTLEPOOL.

Such a soil is fertile when drained, and it is only necessary to prevent the waters from the neighbouring lands overspreading it, or to contrive means to carry off what falls in rain, and is not required to nourish the crops: it is not rendered wet by the action of the underground springs, and may be effectually drained by penetrating through the clay, and letting off the water into the under-stratum where this is of a porous quality, as chalk or such material. The surface of clay is often cut into drains, which are taken in a diagonal direction across the piece of land operated upon; these are made at about 15 or 20 feet apart, and usually about 2 or 3 feet in depth; they are often filled in with loose stones, and again covered up. Drain tiles are admirably adapted for grass land, as well as that under the plough; they are about 13 or 14 inches in length, 4 inches in width at bottom, and a little more in height; they have an arched channel for the passage of the water, 3 inches in width at bottom, and 4 inches in depth: the drains are cut just large enough for their insertion, and not deeper than is required to prevent their being disturbed in the ordinary process of cultivating the soil above. When the tiles are put into the channels, and laid with a proper current to discharge into the drain prepared at their lower extremity, some straw is laid over them to prevent any loose earth from falling in or choking them up: in general, 1000 tiles are put to an acre, and the cost of draining that quantity of land varies from 8*l.* to 4*l.*

Another common practice is for the drainer to take out a spit of clay with a wedge-formed spade or tool, and then to deepen it by another of the same form but smaller, after which he uses a scoop to remove any crumbs that may have fallen down: the drain when finished presents the section of a wedge 30 inches deep, 1 foot wide at top, and only 2 or 3 inches at bottom, and indeed the narrower it is the stronger it is. It is then filled in with brushwood to the height of 10 inches, and covered with long wheat-straw twisted into bands, which are carefully laid in by hand; after this the earth is thrown on, and the

first portions trod gently down, the remainder spread and levelled over it. Where there is an impervious bottom, the drains are often cut 4 feet or more in depth; they are then made proportionately wider, and filled up within 12 or 14 inches of the surface; where the depth does not exceed 5 feet, a width of 2 feet at top is amply sufficient; the width should, however, be increased 4 inches for every foot in depth, and that at the bottom be 20 inches. A great variety of tiles are now used for the purpose of draining; some are cylindrical, the upper half being perforated with small holes to allow the water to pass into the channel formed by laying one-half of the pipe over the other; they are very durable and effective when properly laid down.

When the land abounds with springs, or is subject to the oozing out of subterraneous waters, the draining must be effected by a different method. Springs have their origin from the accumulation of the rain water, which, falling upon the earth, after passing through soils of a porous nature, descends to a bed of clay, close gravel, or some other water-bearing stratum, upon which it glides or runs down the sloping bed, until it crops out at the surface of the ground, generally in some valley, where it forms a run of water. In the chalk districts, the water rises to the slant line of its drainage, or rather stands at the level at which it can drain off; and where a considerable detritus has been deposited upon its bed, the natural oozing out of the water from these springs is prevented, and being penned back, they are forced to find an opening elsewhere.

Wherever a ditch is cut on the slope of a hill at a level, to tap the strata in which the water stands, there it will flow out and effectually drain the soil above it, as has been proved by constant experience; in sinking a shaft or tunnel in the chalk districts, below the ordinary standing of water in the neighbouring wells, the whole has been drained dry for many miles: therefore, to drain a valley which suffers from floods or inundations produced from such causes, it is only necessary to have a catch-water drain made at the foot of the hills which skirts it, and cut sufficiently deep to receive the water which will pour into it.

Descending waters are readily got rid of, by collecting them into a stream before they injuriously overspread the plains below; there are many instances of a valuable level being ruined by the filling of the ditches with water, producing weeds and vegetable matter, which in decaying give out gases of the worst kind, in consequence of the natural drain or river being raised or penned up, which elevates the level of the springs by forcing them backwards; whenever this occurs a new catch-water drain should be sunk, and a free discharge for all the waters which descend from the high ground kept open. If this drain passes through sand or a porous soil, it must be puddled at the sides and bottom.

It is not uncommon in many parts of Kent, where the chalk is capped with a stiff clay and flints, to drain the surface by sinking wells through the clay, and filling them up with stones: the water which falls upon the surface is directed into these artificial cavities, and led off to the chalk, where it sinks to the level of the water-bearing stratum, or to the height of its slant line, which finds an outlet or natural discharge at the toe of the hills, or in some fissures of the chalk. This clay is supposed to be the alumina held by the chalk before its decomposition, or rather before it was dissolved, and carried away by the waters which acted upon it: that a great height has been reduced from both the North and South Downs is evident from the quantity of flints which remain on the surface, and the loftiest parts of these ranges, which are most exposed to the action of the weather, abound with them. Wherever pits can be sunk to arrive at the chalk or the limestone, there is no difficulty in obtaining a free and perfect drainage.

When a morass or a peaty ground is to be drained, the several strata which it reposes upon should be examined by boring, and if, as is often the case, a layer of clay intervenes between the limestone and the mossy surface which holds the water, by tapping the clay in various places well selected, the whole of the water will be discharged and sink away.

Tunnelling under rivers presents very considerable difficulty, as has been experienced in that under the Thames, and it could not have been effected, but for the shield contrived by Mr. Brunel, which consisted of twelve frames, each having three cells that could be opened and shut at pleasure.

Each of the twelve frames, one of which is shown in the cut, had boards 3 feet in length and 4 inches in thickness, called polling-boards; these were supported and maintained in their position by screws, to the number of fifty-four in each frame. When it was required to take out the earth, one of these boards only was removed at a time by the

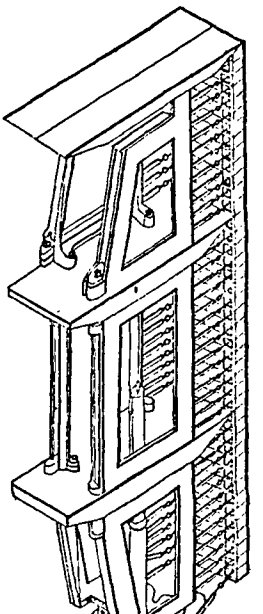


Fig. 2904.

workmen employed; by this means a firm buttress was formed, which resisted the inward pressure of the earth, as progress was made in the tunnel: for a further description of the application of this shield, we must refer to p. 522. The brickwork which lined the bottom, sides, and arches of the tunnel, were completed up to the shield before it was pushed farther along.

Wherever large sewers or drains are required to be made under the beds of navigable rivers, no better nor safer method can be adopted than that of the shield; the workmen are protected by it, and a great irruption cannot take place suddenly, nor without giving ample warning to allow them to escape.

CHAP. XXIX.

ON THE CONSTRUCTION OF MACHINERY.

When machines were formed of wood, the art of the millwright was required to put together the various movements, and other portions of his work, in such a manner that they resisted every strain to which they were subjected: since the universal introduction of iron for this purpose, he is now only required to prepare moulds for casting them; still there are occasions when it is necessary for the civil engineer to have his machinery constructed as formerly, and it is then important that the work be properly performed.

It is necessary that the ram of a pile-engine should be suspended

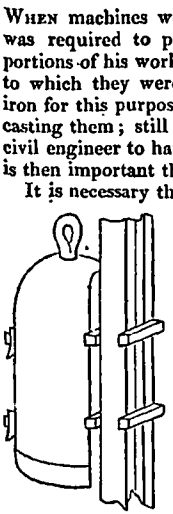


Fig. 2905. RAM.

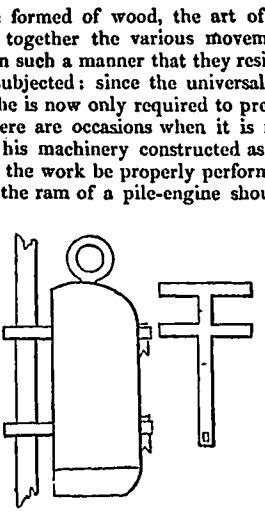


Fig. 2906. RAM.

Fig. 2907. RAM.

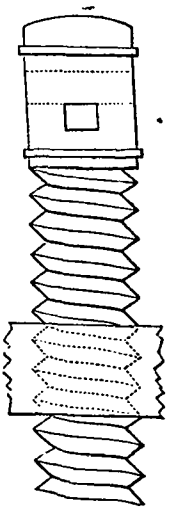


Fig. 2908. SCREW.

so that it falls perpendicularly in the groove prepared to direct its motion, and this has been admirably and simply effected by attaching to the back of the ram two frames in the form of a H, the arms of which serve as a guide when rising or falling. Our limits will

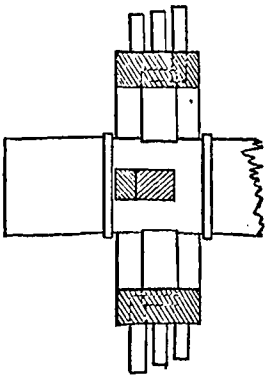


Fig. 2909.

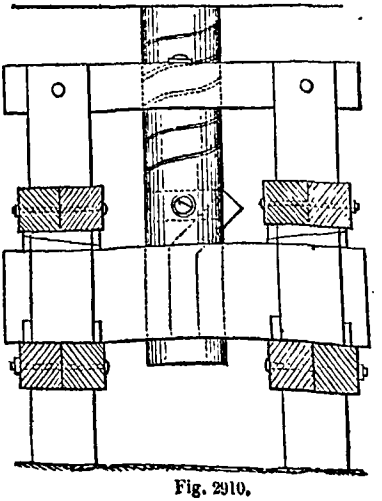


Fig. 2910.

not permit us to detail the construction of many portions of those machines, the principles of which have been already described: we can only allude to the movements of a few of those most generally in use.

In forming a screw the hardest wood should be selected, as that of the box tree, or any other of equal strength, which is not likely to warp or get out of form. As the power of the screw depends upon the correctness with which the thread is turned, the primitive cylinder, which the inclined plane is to surround, should be worked very accurately before it is offered to the lathe or cutting machine.

When the screw is mounted to serve the purposes of a press, the standards which confine its action must be braced and firmly held together; the braces at the sides may be made to serve as supports and ties.

Where two screws are required to lift the same plane, great attention must be paid to the cutting of the spiral threads around them, or they will work unequally, and

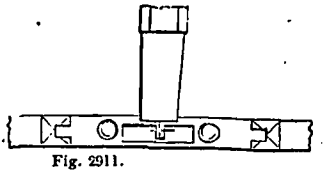


Fig. 2911.

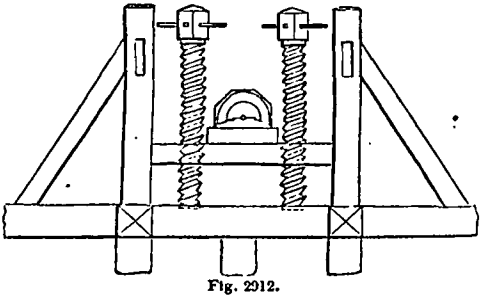


Fig. 2912.

throw greater stress upon one thread than the other.

The framework upon which the spindles of wheels are mounted, as well as the axles, should be wrought with the greatest nicety, and the staves of the trundles and the cogs of the wheels made either of hornbeam wood or lignum vitæ: in mounting a trundle Perronet used two triangularly framed stands, into the heads of the upright posts of which the gudgeons worked.

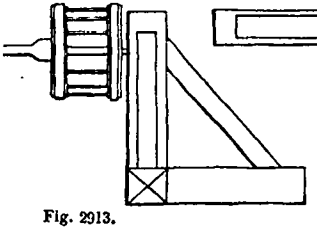


Fig. 2913.

Fig. 2914.

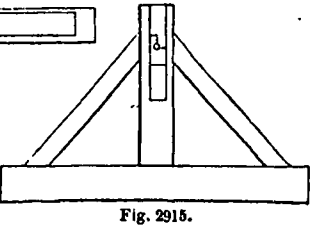


Fig. 2915.

When a beam is to be lifted perpendicularly, the wipers require to be fixed firmly, otherwise the cams on the turning wheels, which produce its motion, and occasion it to rise and fall successively, will not act with that precision which is required for stamping or pounding, to which this motion is particularly applicable. After passing the wipers through a mortise made to receive them, they require firmly wedging from the opposite side.

Tread Wheels are of very simple construction, and serviceable in moving pumps or other machines; they have a long iron shaft, with four or six wheels about 40 inches in diameter, 24 spurs or starts, like those of an undershot water-wheel, being fixed upon it; these spurs are 8 or 9 inches in length, with footboards attached by strong screws: the useful effect of a tread mill has been calculated upon the supposition that a man can lift his own weight 12,000 feet high in a day; supposing him to weigh 150 pounds, the total weight lifted would be equal to 1,800,000 pounds raised a foot in the course of a day's work of 8 hours; walking wheels are variously made, and there are several with footboards attached to the levers that move the spindle round.

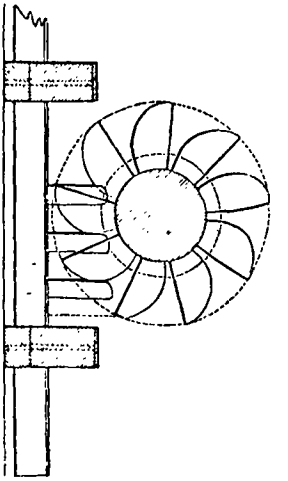


Fig. 2916. WIPERS.

The cams are set out at the required distances on the turning wheel or cylinder, and are repeated as often as motion is considered necessary; the three stampers shown are raised alternately, by attending to the several positions in which the cams are placed.

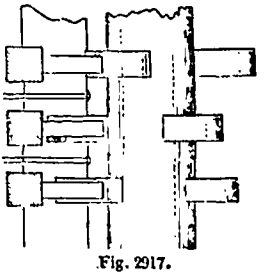


Fig. 2917.

M. Camus, to whose valuable treatise on the Teeth of Wheels we have so frequently referred, considered the best form that could be given was that which placed them always in such positions that they equally favoured the action of each other; the smaller wheels of a machine are sometimes made out of a single piece of hard wood, with the teeth cut out of the solid.

A crown wheel and pinion, constructed of timber, must be so framed, that every portion of its rim or periphery is strongly held and braced together: this cannot be more effectually done than by crossing two timbers at right angles; through the opening in the middle, the shaft may be secured to the frame, and when it revolves motion is conveyed to the machinery in an easy and steady manner.

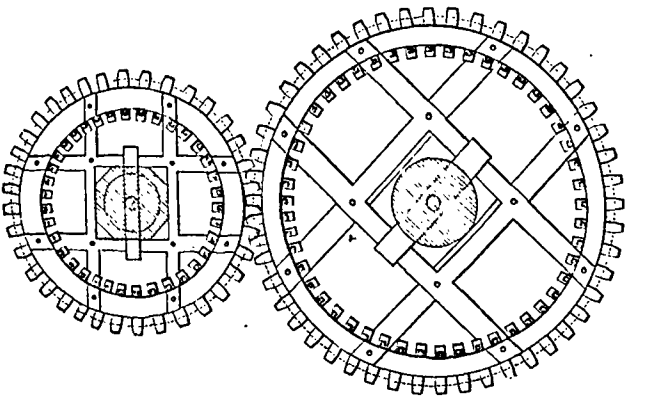


Fig. 2918.

Additional strength may be given to the arms on the under side of the large, and upper side of the small wheels; the cogs are formed of hornbeam, mortised and tenoned into the periphery of both wheels, the proportion of which has already been described.

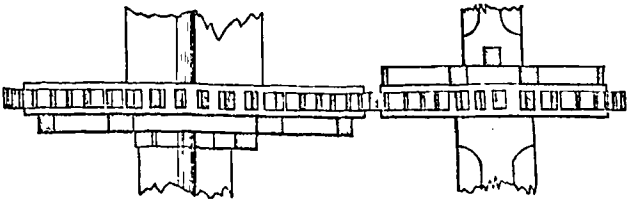


Fig. 2919.

To secure the wheel on the shaft which turns is easily effected by wedging: all these operations require attention to the strength of the several materials employed: they should be well seasoned, and not likely to shrink from their original dimensions. Where a spur-wheel is to work in a crown-wheel below, its spindle may pass into the same timber that the gudgeon of the upright shaft works in, if it be securely framed and braced to resist any lateral movement. The rims of these wheels may be further strengthened by inner circles made fast to the outer, and the upright shaft left square where it passes through the frame of the wheel.

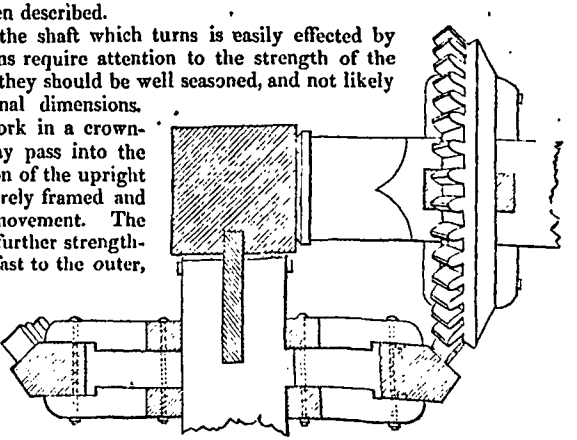


Fig. 2920.

Wheels which engage each other should be braced in proportion to the stress and action they are subjected to: where the dia-

meters are small, the arms at right angles may be sufficient; but in those of greater diameter, the arms will often require diagonal braces from one to the other, and these again strutted to the outer rim; the more solid the framing, the more exact the movement; great attention is required to effect this.

In the construction of a chapelet it is necessary to consider, the power that is to be employed; it has been shown that at the building of the bridge of Orleans one put in motion by twelve horses made 140 turns in an hour: the number of cogs upon the great wheel was 115, and of trundles upon the lantern 12: the height as well as width

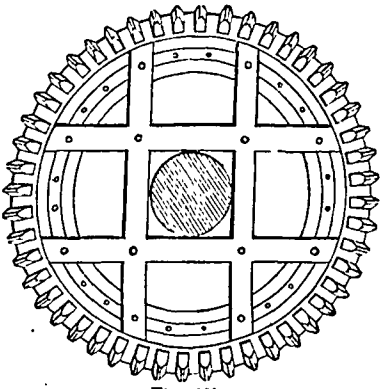


Fig. 2921.

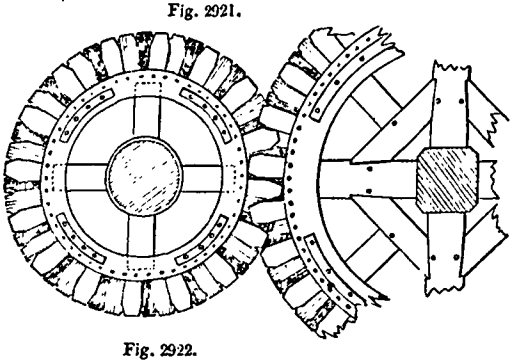


Fig. 2922.

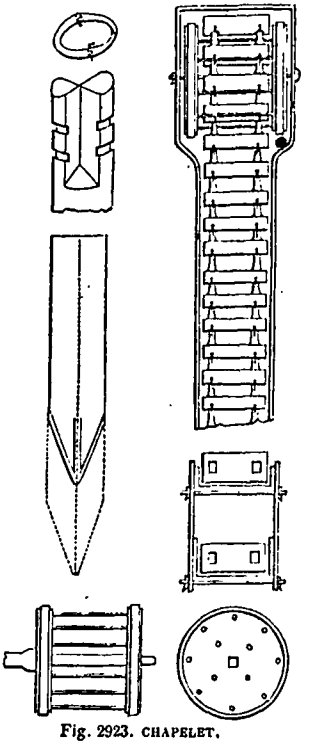


Fig. 2923. CHAPELET.

of the buckets was 6 inches. As the chain passes over the staves of the lantern, it is raised with its load by the turning of the latter: the outer frame is generally made of wood, the sides braced together at convenient distances, and trapped with iron.

The Archimedean screw is surrounded by a cylinder made generally of wood; the spindle, round which the screw traverses, may either be made of the same material or of iron: this ancient and very useful power has already been described.

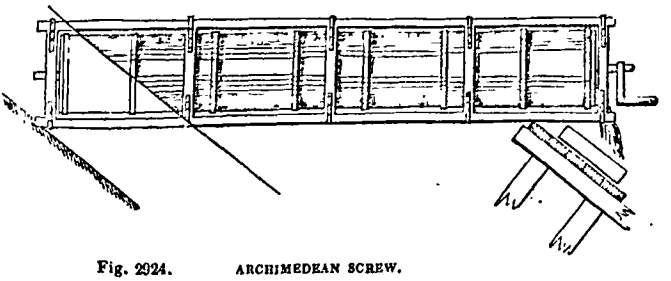


Fig. 2924. ARCHIMEDEAN SCREW.

Pumps are often made of timber, when there is a difficulty of obtaining those of metal: but the trough or pipe in which the plunger works can rarely be made sufficiently water-

and air-tight to prove very effective. In pumping water out of foundations or trenches, the bottom of the pipe should be pierced with holes, to prevent the mud and soil from entering: the buckets and plungers may be formed out of elm or beech, and the handle connected by a wooden rod, the strength of which is considerable, particularly when made of deal.

The Construction of a Vessel belongs to the ship-builder rather than the civil engineer, although it is of the utmost importance that the latter should be acquainted with the principles upon which it is set out: plans, elevations, and sections through every part are required, before any of the timbers can be rightly proportioned. The safety of a ship requires that the timbers should uniformly cross the keel, and that the frame be filled up so as to form one compact body of timber; to trace the changes which have been made in the sections of ships by different nations, and at different periods, is of the highest value, and still occupies great attention.

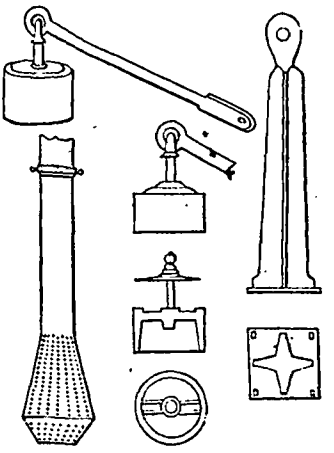


Fig. 2925. PUMPS.

The Displacement of a Vessel, or the cubical contents of that part which is below the water's surface, may be calculated from the principle that a body specifically lighter than water will sink until it has displaced a portion of the fluid equal in weight to the entire body itself: in designing a boat or vessel, the first object is to form as accurate an estimate of this weight as possible.

The universal joint may be formed out of any hard wood, and the action of the concave upon the convex ball guided in any direction required; the strength of the globe is sufficient in itself to resist fracture; but the casing which works upon it requires to be braced or strengthened by a metal rim, into which the movable arm may be let.

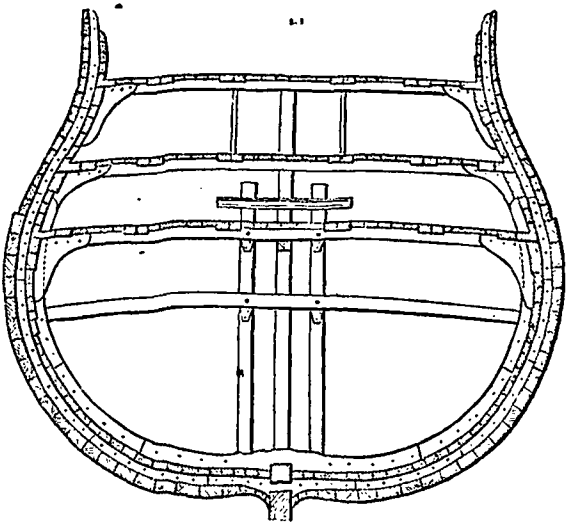


Fig. 2926. SECTION OF A VESSEL.

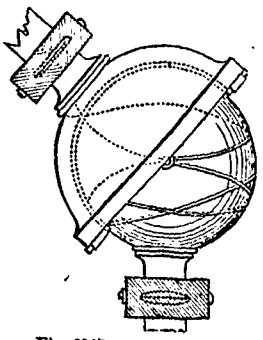


Fig. 2927. UNIVERSAL JOINT.

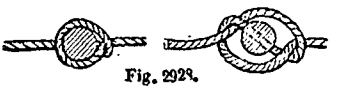


Fig. 2928.

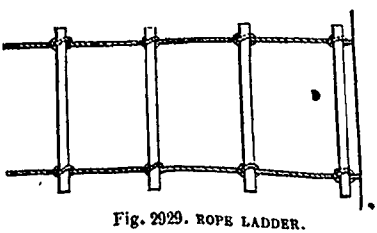


Fig. 2929. ROPE LADDER.

Rope ladders are frequently in request by the mechanic, and are easily made by passing the staves through a slip-knot, and fastening them in their position.

CHAP. XXX.

RAILROADS.

The steam-engine being the means by which carriages are propelled on a railway, it would be natural that the first men consulted upon the best method of laying out a line should be those most acquainted with the uses of the new motive power; but time and experience have extended this knowledge, and created many practical civil engineers, whose added stores of information, skill, and ingenuity, will, it may be fairly hoped, very considerably lessen the expenditure for all future railroads. The first operation in these new national works is an accurate survey of the country to be passed through, which should extend to a considerable distance on each side of the intended line: there should be scope enough left either way for the engineer to benefit from the levels of the land he is desirous of crossing. The land-surveying and the levelling should progress together, one party mapping while the other lays down the rise and fall; the cuttings and embankments must next be calculated and made to balance as nearly as possible, care being taken that sufficient land is mapped to extend the base of the embankments, and, where deep cuttings are necessary, that a width at top is provided, to allow for the talus or slope, as well as for any casual slips or shrinking to which the various earths may be subject. Should the embankments not require all the earth from the cuttings, proper situations must be secured for the deposit of the surplus; and, if the cuttings do not afford sufficient for the embankments, the earth must be obtained at the nearest and most convenient spot: these and various other points dependent on locality must be well considered at the time of laying down the map, that, when the period of execution arrives, there may be no obstacle to the pre-arranged plans. Before the engineer can finally determine the width of the respective cuttings, it will be necessary to examine into the nature of the various earths through which his operations are to be carried, as upon this must depend the quantity to be removed, and consequently the widths to be set out. When a cutting is made through clay, the slope in some instances is only required to be 1 to 1; but if in a constantly wet state, it will slip, even if 3 to 1 is given; soapy shale will slide when at a much greater slope than 5 to 1: chalk will stand nearly vertical, and the more it approaches that position, the less it will be affected by the weather. Sand has been found to stand with a slope of 1 to 1: on the Newcastle and Carlisle Railway, where the depth of cutting is upwards of 100 feet, it stood well with the talus of 1½ to 1. Gravel and dry soils stand well with a slope of 1½ horizontal to 1 perpendicular, when the height does not exceed 40 feet; but in wet seasons the greatest caution is required to make most of the soils stand, whatever slope be given them: 8¼ feet in width requires for each mile in length an acre of ground; 16 feet 6 inches, or a rod in width, requires two acres, there being 320 rods to a lineal mile, and 160 square rods to an acre. Thus there is no difficulty in ascertaining the quantity contained in the cutting for a general estimate; when the slope and the depths have been determined on, the mean width multiplied by the depth will give the cubical content. Where the embankments should cease, and the construction of a viaduct begin, or where the open cutting should give way to the tunnel, are points of great importance for the decision of the engineer.

As it is usual to estimate all earth-works by the cubic yard, it is advisable, wherever practicable, to take all the dimensions in yards, and their decimal parts; and, by calculating 4840 square yards as making an acre, and 1760 yards in length a mile, there would be a great facility afforded in arriving at the desired quantity. Numerous tables are, however, constructed, by which the quantities are ascertained, without the trouble of calculation. It must be remembered that clay, as well as some other earths, will require a larger quantity of cutting to form the embankments than they cube to; whilst with some common earths there is an increase of at least ten per cent. in the quantity, when first used, and before it has time to become consolidated.

When the railroad is made, it must be entirely free from water: drains must be cut on each side, and conducted to watercourses constructed so as readily to receive all that passes by them: in soils like that of the Chatmoss, varying in depth from 10 to 34 feet, and resting on a substratum of clay and sand, considerable difficulty is experienced in forming the embankments as well as the cutting In that instance the operations of the engineer extended over a length of 4 miles; drains were cut at every 5 yards, and as soon as the water had passed off, and the moss become dry, it was removed, and the embankments formed of it, four times as much being required in the dry state to fill up the same

quantity of yards as when wet; other drains were then cut on each side the embankments, 2 feet deep, and when the water had drained out of the moss under the intended roadway, double layers of hurdles, covered with heath, were laid upon it, and on these a stratum of ballast. The drains were entirely effectual; 670,000 cubic yards of moss in its natural state when dry were required to make 277,000 cubic yards of embankments, so great is its capacity for water.

When the fall is 10 feet in a mile, the gradient is 1 in 528; when 20 feet, 1 in 264 feet; and when 30 feet per mile, a third, or 1 in 176; when the gradients are established, allowance can be made in the calculations of quantities, and the average depths and heights determined on.

The plans and sections of the intended line being prepared, the quantities of earthwork may be accurately ascertained, and contracts made for the cuttings and embankments, and the centre of the line being marked out, the operations of cutting may immediately commence. The first contractor usually provides engines, rails, waggons, and whatever is required for the transport of the earth, and sublets the work to gangs of navigators. Horse-power has been abandoned, the locomotive or stationary engine, drawing the waggons at the rate of 8 or 10 miles an hour when loaded, being much more convenient. Much judgment is required in establishing the situations for the waggons to tip or shoot their load: where the depth of cutting is considerable, inclined lines may be formed, along which very little labour is required to move the carriages. One man will throw into a waggon in the course of a day 15 cube yards of stiff clay, or 25 of sand, and, according to the nature of the ground, from 60 to 90 men can throw up and load 1000 cubic yards in that time.

Ashley Cutting, on the Great Western Railway, about 5 miles on the London side of Bath, at the base of Kingsdown Hill, is 23 feet above the level of Box Brook, which runs in one of the two valleys separating the parallel ridge of the upper oolite that caps the hills in this district, and upwards of 800 feet above the level of the sea. The top of Kingsdown Hill, behind the cutting, is above Box Hill, where the tunnel passes, and the land slopes down to the railway at the rate of 1 in 14, exposing an inclined plane of at least 4000 feet in length to the action of the atmosphere. The cutting was made through a drift from the high lands, and not through the original stratification: and after its completion, the upper portion of this deposit slipped, producing considerable inconvenience: this arose from its tendency to absorb water, from which it had no means of clearing itself, the lower portion of the bed, on which it rested and abutted, being removed. To remedy this the whole was cut to a slope of 4½ to 1, and shafts were sunk until they pierced the water-bearing strata; these were connected with several headings, driven on the surface of the marl, parallel to the railway, which most effectually decreased the quantity of water; but 1500 yards of shafts and headings were driven at a cost of 30s. per yard run before this was entirely accomplished, or the drift could be made to stand at a slope of 2 to 1.

Equalising the Excavations and Embankments, so that the parts excavated will furnish earth sufficient to fill up the valleys or low ground to be crossed: to effect this we must resort to a system of successive approximations, by assuming different slopes, and shifting the line to one side or the other till we arrive at the proper result. The solid contents of both excavations and embankments must be calculated, bearing in mind that the earth in its natural state occupies less than when broken up, and that an artificial embankment settles considerably: this allowance must depend upon the nature of the soils. The axis of the road is then set out by piquets, and its width with stakes, on which is marked either the height to be filled in, or the cutting to be made.

The removal of the earth by the most economical method is the next consideration, and then the inclination to be given to the side slopes: when the earth is a mixture of clay and sand, 2 of base to 1 of perpendicular, and where the latter material predominates, a greater slope is necessary: in solid rock the sides may be left nearly or quite perpendicular; but it must also be remembered that slaty rocks disintegrate very rapidly when exposed to the action of the frost, and it is better to cut them into steps and cover their surfaces with vegetable mould, on which grass seeds should be sown.

The stratified rocks, which dip towards the horizon, being liable to slip when cut through, require great attention; where clay and sand alternate, they must be effectually drained, all the surface water collected, and the springs working in them conducted away, for which purpose deep trenches must be cut, and filled in with gravel or loose stones with an easy fall.

Drainage of the subsoil is also necessary, and this is often performed by making a longitudinal drain under the roadway, or by side-cuttings in the manner of catch-water drains on the slopes, running them obliquely along the surface, and then allowing them to empty into the cross drains or natural watercourses.

In marshy soils it is often requisite to make an entirely new artificial bed to receive the roadway, and this is best done by taking out the spongy elastic earth, and substituting a harder material.

Gradients, or the proportionate ascent or descent of the several planes constructed on the

railway, demand from the civil engineer very considerable attention. In the Treatise on Locomotive Engines by Chevalier F. M. G. De Pambour, the author, after stating that inclined planes are a great obstacle to the motion on railways, supposes if a train of 100 tons be drawn by an engine on a level, the friction of the carriages will produce a resistance of 8 lbs. per ton, and consequently the power required of the engine will be 800 lbs. He then supposes the same train ascending an inclined plane at $\frac{1}{100}$; on that plane, besides the resistance owing to the friction of the waggons, a fresh resistance occurs, which is the gravity of the total mass in motion on the plane: that gravity is the force by virtue of which the train would roll back if it were not retained, and is equal to the weight of the mass, divided by the number indicating the inclination of the plane. If therefore, in this case, the load of 100 tons be drawn by an engine weighing ten tons, the total mass placed on the inclined plane will be 110 tons, or 246·400 pounds; thus its gravity on the inclined plane at $\frac{1}{100}$ will be $\frac{246 \cdot 400}{100}$ lbs. = 2·464 lbs. The surplus of traction required of the engine on account of that circumstance is therefore 2·464 lbs.; and as on a level one ton load is represented by eight pounds traction, 2·464 lbs. represents the resistance that would be offered by a load of 308 tons on a level. The engine which before drew 100 tons must now draw 408 tons, or must exert the same effort as if it drew 408 tons on a level: upon this data the author above quoted has calculated the resistance on inclined planes; some writers have given the angle of repose as 1 in 280; and the Irish Railway Commissioners have stated that at the angle of 1 in 140 a velocity is acquired which has a useful practical effect.

On the London and Birmingham line of railway, where the plane for a considerable length was 1 in 75, the trains attained a velocity of thirty miles an hour. A gradient of 1 foot per mile is equal to a rise of 1 in 5280; of 10 feet, to 1 in 528: of 20 feet, to 1 in 264, and tables are calculated showing the inclination up to 60 feet, or 1 in 88; and other tables have been drawn up, to show the lengths of equivalent horizontal lines to gradients, from 1 in 90 to 1 in 1500.

Gradient.	Ascending.	Descending.	Mean.	Gradient.	Ascending.	Descending.	Mean.
1 in 90	2·66	1·00	1·83	1 in 200	1·75	·83	1·29
— 95	2·58	1·00	1·79	— 250	1·60	·83	1·21
— 100	2·50	1·00	1·75	— 300	1·50	·83	1·16
— 110	2·36	1·00	1·68	— 350	1·43	·83	1·13
— 120	2·25	1·00	1·62	— 400	1·37	·83	1·10
— 130	2·15	1·00	1·57	— 500	1·30	·83	1·06
— 140	2·07	1·00	1·53	— 750	1·20	·83	1·01
— 160	1.94	·83	1·43	— 1000	1·15	·85	1·00
— 180	1·83	·83	1·33	— 1500	1·10	·90	1·00

To calculate the resistance of the trains on an inclined plane, we have in the work before alluded to a very useful table for engines weighing from 8 to 12 tons, with the load they draw. Where the engine weighs 8 tons, the following table may apply.

Equivalent Load on a Level, the inclination of the Plane being —

Load in Tons.	$\frac{1}{360}$	$\frac{1}{300}$	$\frac{1}{300}$	$\frac{1}{200}$	$\frac{1}{150}$	$\frac{1}{100}$
25	44	48	56	71	87	117
50	83	91	105	131	158	212
75	122	133	153	191	230	307
100	161	176	201	251	302	402
125	200	218	249	311	373	497
150	239	261	298	371	445	592

By such a table we can observe the resistance of the trains on inclined planes.

Width between the Rails. — On the first establishment of railways, the clear width between the rails was fixed by parliament at 4 feet 8½ inches, which is that of the Liverpool and Manchester line; but since the year 1836 this has been optional with the engineer, and the Great Western is 7 feet between the rails. The width between the two lines of railway is ordinarily the same as that between the rails; but upon the London and Birmingham line it is 6 feet, though, for all practical purposes, 4 feet 8½ inches has been found sufficient. A proper width outside the rails is, however, exceedingly important, in order to obtain the requisite stability or firmness in the embankments for fixing the blocks and rails.

Whether the broad or narrow gauge will eventually prevail, it is difficult to decide; but certainly the latter is the most economical in construction, and, if equally answering the

purpose with the other, it should on that account be preferred. When the distance between the rails is increased, every additional inch in width adds to the expense, not only for the land on which it is set out, but also from requiring stouter sleepers and rails of a greater weight; the length of the axles of both the locomotives and the carriages they draw must also be prolonged, and consequently rendered more likely to fracture, if their strength be not greatly increased; the draught is more immediate from the middle of the narrow than from that of the broad gauge.

Foundation for the Stone Blocks and Sleepers. — The surface of the way transversely should be convex, with a rise of about 3 or 4 inches in the middle, to throw the water into the lateral drains, and previously to placing or bedding the blocks, a stratum of broken stones should be spread over the whole to the depth of a foot, through which the water can penetrate into the brick drains previously constructed beneath it: another stratum of finer stone with sand is laid, and after being well rammed is levelled to form a firm foundation. The blocks are of a hard and compact stone, often of granite; they are drilled for the reception of the trenails and made level to receive the chairs; but if great care is not taken in setting them they will sink and require to be reset: they are now usually bedded by means of a machine containing a lever, about 20 feet in length, with its fulcrum at a sufficient distance from the end to raise the block intended to be set about a foot high from the ground; and while one man is manœuvring it, another, as often as it is lifted up, throws under the block a layer of sand or fine gravel, until it is not only level transversely, but ranges with the others along the line, and when once placed it should not again be moved. Where the ground is not very firm, wooden sleepers are laid across the way, from one side to the other, made of larch or other durable timber, and of a scantling not less than 12 inches by 6: they were at first cut out of round timbers or Scotch fir, 12 or 13 inches in diameter, and after one cut was made in them, they were laid with their flat side downwards across the road, at a distance of 3 feet from centre to centre. Transverse with longitudinal sleepers over them, extending the whole length under the rails, make the most stable arrangement, and are now generally adopted: it is highly important to prevent any sinking of the rails after they are once set, and it is a false economy that dispenses with the timber substructions, which form an extended base to receive the weight passing over the rails.

When, however, stone blocks are used in preference to timber sleepers, they should be made perfectly level before the chairs are set upon them: two holes, about 2 inches in diameter, are then drilled into them, for the purpose of inserting plugs of heart of oak, which, when firmly driven in, are bored with an auger, to receive the iron pins which fasten down the chairs. In many instances the former have been dispensed with, and a piece of tarred felt inserted between the bottom of the chair and the top of the block: oak pins engine-turned have also been used, and if well driven, they are found to render the chair tight and firm; if tarred over after their heads are cut off level, they will last many years in a sound state.

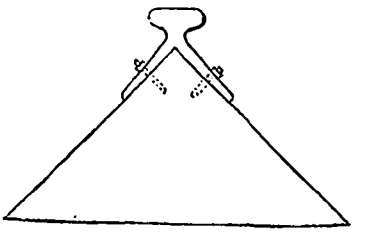


Fig. 2930.

Triangular sleepers, laid longitudinally upon others which cross the railway, are in some instances preferred: as in the fixing the iron rails chairs can be dispensed with, and greater strength can be obtained from the same quantity of timber; for there is no better form to resist compression than a triangle placed upon a broad base.

In the construction of the Great Western Railway stone blocks were dispensed with, longitudinal rails of American pine being substituted for them; they were 14 inches in breadth, from 6 to 7 inches in thickness, and laid on alternate double and single transverse ties. The double ties were each 6 inches in breadth and 7 inches in depth; the single were 6 inches in breadth and 9 inches in depth: two beech piles, 10 inches in diameter, were driven between each double pair, and two others by the side of each single tie, the rows being about 8 feet 6 inches apart. In cuttings the piles were driven 8 or 10 feet, but on the embankments, or where the earth was made, they were usually driven through into the subsoil.

The heads of the piles were secured to the double and single rows of transverse cross ties or sleepers by iron bolts with screws and washers. The longitudinal timbers, 14 inches in width, were laid down upon the cross ties, and then firmly bolted to them with screw bolts and washers; the head of the bolt and washer, being counter-sunk in the longitudinal rail, and passing through the transverse ties, were secured below: two bolts were used when the timbers were double, and one at each point of intersection of the single timbers. The longitudinal timbers being bolted securely to the transverse ties, the latter were again secured by bolts passing through the head of the piles.

After the cross ties and longitudinal timbers were all securely placed, finely screened

sand or gravel was driven or packed under them by means of pointed beaters, which was continued until the timbers were strained upwards of half an inch or more in the middle and made to curve; they were then adzed down to a level, and a plank of hard American oak, 8 inches broad and 1½ inch in thickness, was laid upon a bed of tar, the whole length of the longitudinal timbers, and nailed down in two rows with 2-shilling nails, their heads being well punched in. The oak plank was then planed to a surface throughout, and the iron rails laid on it with great care, each joint being fitted very nicely, with due allowance for expansion and contraction; the iron rails were fastened down by screw-bolts passing through a piece of felt, the American oak, and then into the longitudinal timber: the screws on the outside of the rails had square heads, but those on the inside were countersunk, so as to avoid any interruption to the flanges of the wheels as they passed along. When the outside screw had been so tightened as to draw the rail close down to the oak plank, and the inner screws also made as tight as possible, a heavy roller, weighing 10 tons, was moved several times over the rails, and as it passed the screws were again turned until perfectly tight. The gauge of these rails is, from centre to centre, 7 feet 2½ inches, and the width between each pair of rails in the middle 6 feet; so that from the centre of the outside rails, where the double line is complete, is 20 feet 5 inches.

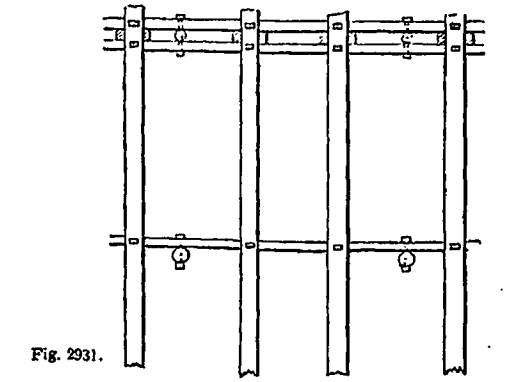


Fig. 2931.

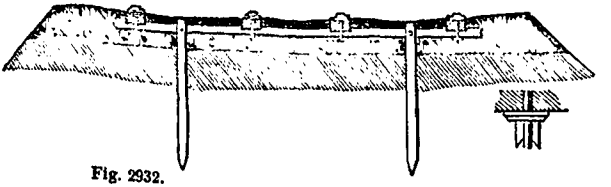
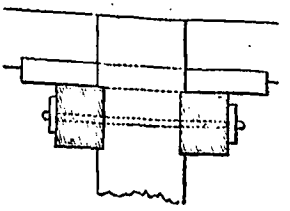


Fig. 2932.



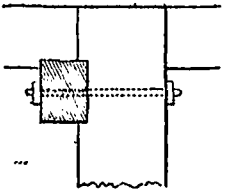


Fig. 2933.

Fig. 2934.

The piles are for the purpose of holding down the sleepers, and the packing under the timbers which cross the railway is to give them a pressure upwards, to enable them in some degree to resist the weight of the carriages; it has been stated that this springing of the timbers adds considerably to their stability; and, undoubtedly, the pressure upon a curved timber would throw the weight towards the ends, and deposit it against its abutment, which would be the sec-

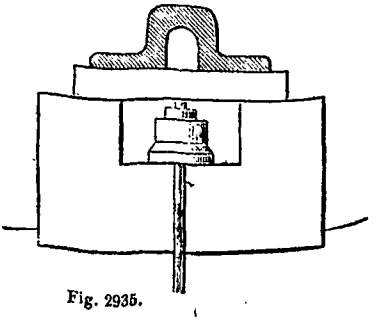


Fig. 2935.

tional end of the adjoining one, as long as the pile maintained its retentive power. This timber foundation required for every mile of double line 420 loads of American pine, 40 loads of oak, 6 tons of wrought-iron bolts, and 30,000 screws.

Rails, when of cast-iron, are more brittle than when of malleable metal, and consequently require an increased area in their section to be equal in strength to the latter: they are durable, resist for a long time the action of the wheels, and, from the hardness of the metal, oppose little or no obstruction to them: but the malleable iron, from not being so subject to fracture, is now usually preferred. The width of the rail at top is about 2¼ inches, which is that now given to most wheels, and considered sufficient for all purposes. It has been estimated that the wear and tear or waste of the rails is about $\frac{1}{10}$ of a pound per yard per annum, or that $\frac{1}{84}$ inch in depth is annually worn away; but this must in a great degree depend upon the quality of the iron, and many other attendant circumstances: their length is about 15 feet, and the expansion and contraction in our temperature is estimated at equal to $\frac{1}{2000}$ of that length, or $\frac{1}{11}$ inch. In comparing the strength of rails great differences are observable from the various kinds of iron used; when diversities of metal in proper proportions are employed, the rail is stronger, with the same weight of iron, than when composed of one metal. It is admitted that those of malleable iron are easier kept in order; that, extending over several chairs or blocks, there are fewer joints; that they present to the wheels of the carriages a smoother surface, and are also more regular in their decay; that their elasticity being great, they are not so subject to fracture, and will bear considerable change of form without the cohesive power being affected; and that pressure which would crumble down the crystalline texture of the cast-iron flattens the malleable, and renders its powers of resistance greater.

With regard to the best form for the section of a rail, there have been various opinions; it has been ascertained that a malleable iron bar of any length is extended $\frac{1}{100000}$ of that length by the direct strain of a ton for every inch of its sectional area, and when strained by ten tons per inch, or stretched $\frac{1}{1000}$ of its length, it does not regain its form or elasticity.

The Plate Rail, first used about the year 1767 in a colliery near Sheffield, was a flat bar of cast-iron with an upright ledge; it was in 6 feet lengths, and the upright and flat part measured in width 2 inches; they were secured by nails to transverse timber sleepers; they were placed on square wooden blocks, and it was not until the year 1800 that stone blocks were used on the railway at Little Eton, in Derbyshire: some flat rails are cast with a square hole at every joint; through this an iron pin is driven, which enters a wooden plug previously introduced into the stone block; one-half of the pin thus secures the end of each rail, which is in lengths of from 3 to 4 feet. In some cases a return is cast on the edge of the flat part of the rail, which enters a groove cut into the stone, and adds considerably to its steadiness. Wrought-iron rails were first used about 1824; they are now all so manufactured, and rolled out to the form required.

The first Edge Rail was of cast-iron, and used at Loughborough about the year 1789: its upper surface was level, and that below elliptical: a flange on the wheel guided it along the rail; it consisted of a bar of cast-iron, about 3 inches thick, increasing towards the top to a breadth of 2¼ inches, in which the wheel ran: they were either fixed to wooden sleepers or stone blocks, and this description of rail, when its section was that of a parallelogram, was calculated to bear the greatest strain.

Iron chairs, of which there are now many varieties, were a most useful introduction: the first were made with a flat base, of about 7 inches in length, 4 inches in width, and ¾ of an inch thick, gradually diminishing towards the edge to ½ inch: the upper part, which received the rail, had two uprights cast on it, at a distance sufficient to allow the rail to enter between them, when fixed pins were passed through the cheeks or uprights, as well as through the holes in the ends of the rails, which prevented them from moving; they were placed either on stone blocks, 18 inches square and 9 inches in depth, or on wood 3 feet long, 10 inches wide, and from 6 to 8 inches in depth. The chair was fastened down by driving an oak pin or plug through a hole cast on each side, and another drilled into the blocks.

In the year 1816 *Loch and Stephenson* obtained the first patent for an improved rail and chair: the ends of the rails united in a half lap, a pin passed through the two ends as well as the chair, and kept them together. The object of this patent was to fix both the ends of the rails, or separate pieces of which the ways are made, immovably in or upon the chairs or props that support them, and so to place the rails that neither of the ends should

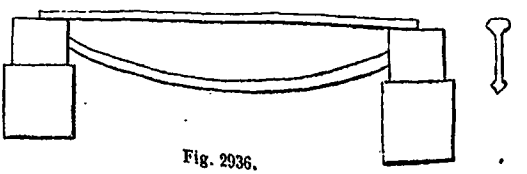


Fig. 2936.

project above, or fall below, the corresponding one of that with which it is in contact, and so to form the union of the rail and chairs, that they should always remain perpendicular: this contrivance relieved the carriages from the sudden jerks to which they were previously subject, and diminished the resistance offered to the wheels in their transits over the rail.

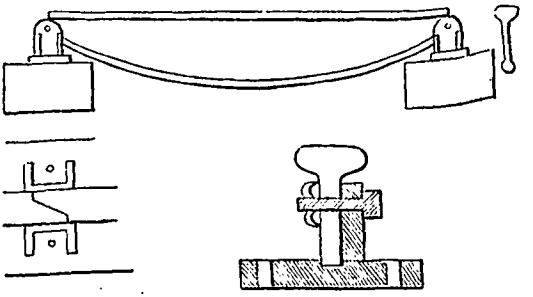


Fig. 2937. LOCH AND STEPHENSON'S CHAIR.

Brunton and Shield's Railway. — The rail is fastened to the chair, which has only one cheek, by a screw-bolt, which draws a concave nutt tightly against a convex protuberance on the rail, holding it firmly against the upright cheek of the chair: the thread of the screw, however, being exposed to the action of the weather, is, in the course of time, apt to break, when turned for the purpose of tightening the joints.

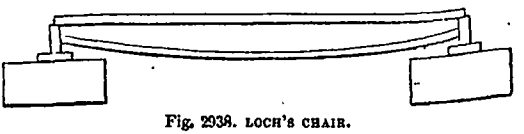


Fig. 2938. LOCH'S CHAIR.

Loch obtained a patent for another chair, in which the pin was dispensed with: the rails were united at the ends by means of a half lap passing each other, when they were set on edge 3 inches: upon the outer side of each rail was a circular projecting knob, and on one of the inner sides a similar knob, which entered a cavity cast to receive it, and prevented the rails from being drawn out in the direction of their length: the rails maintained their proper position, and were prevented from rising by their own weight. Other means have been adopted to maintain the rails on their chairs without a pin; some have round knobs cast on their ends, which enter cavities answering to them, and are kept in their places, thus obtaining a level surface throughout, which is the chief result to be arrived at.

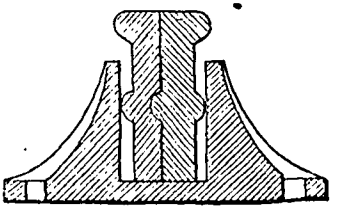


Fig. 2939.

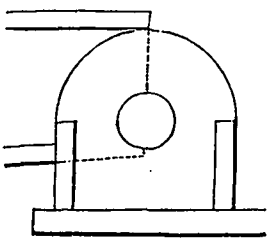


Fig. 2940.

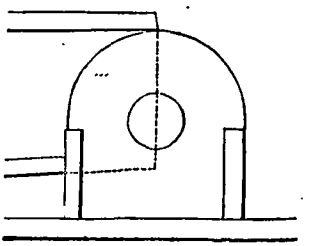


Fig. 2941.

One of the first malleable rails formed by rolling-bars was made in the year 1820, which effected a great change in all that were afterwards manufactured. The process consists of passing bars of iron heated red-hot between two rollers so grooved that they give the required form; the under side of the rail is sometimes made elliptical, by fixing it on a false centre. This kind is usually rolled out into 15 feet lengths, and laid on 3 feet bearings, with their ends formed with half laps.

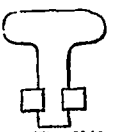


Fig. 2942.

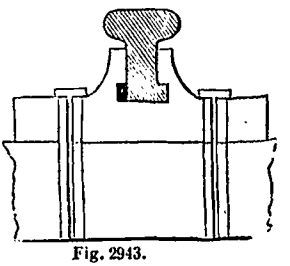


Fig. 2943.

The Liverpool and Manchester line had rails of this description, weighing 35 pounds per lineal yard with square ends, and a square projection on one side, which, by driving an iron key into a hole on the other, force it into a recess cast in the side of the chair to receive it. The key was in form of a wedge, and driven longitudinally.

The chairs were secured to stone blocks, 2 feet square and 12 inches thick, by iron pins driven into wooden plugs, previously inserted in the stone. In Loch's patent the key is driven on each side above the projection at the bottom of the rail, so that it is kept from rising, which became necessary when the rails were made in 15 feet lengths, the alterations

arising from the variations of temperature rendering it difficult to pass the pins through them and the sides of the chairs, as had been done with those of shorter lengths. The joints are liable to become loose from the constant action of the carriages, and the most effectual way of tightening them is to drive wedges of iron along the sides of the rail.

London and Birmingham Railway has a joint or double chair, and a single or intermediate, made of strong grey cast-iron, of the No. 1. quality. The double chair has 2 wrought

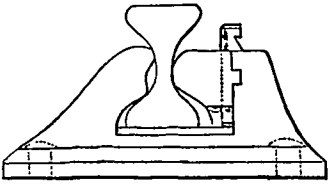


Fig. 2944. SINGLE CHAIR.

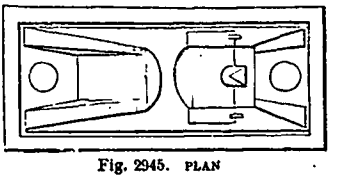


Fig. 2945. PLAN

iron pins, 2 wrought-iron wedge bolts, and 2 wrought-iron keys: the single or intermediate chairs have 2 wrought-iron pins, and 1 wrought-iron key, which are of the best malleable iron.

By a reference to the plan it will be seen that the seat of the rail is convex on the one, and double convex in the other; the side of the chair next to the flanges of the wheels is in contact with the rail at only two points; on the other side, the rail is secured by a cast-iron

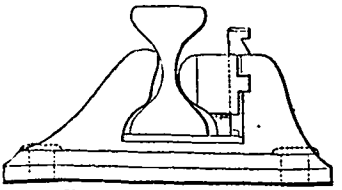


Fig. 2946. DOUBLE CHAIR.

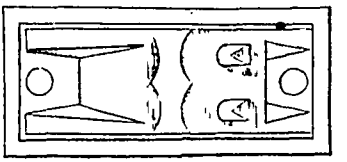


Fig. 2947.

chock of a spheroidal form where it touches the rail; this chock has a step or foot by which it rests on the bottom of the chair, and is wedged into its place by means of a wrought-iron key, which passes perpendicularly into a mortise, one-half of which is cut through the chock, and the other half on the chair.

The chairs were pinned down to the blocks with iron spikes 7 inches long, and $\frac{3}{4}$ inch in diameter, their heads being $1\frac{1}{4}$ inch in diameter. Some of the fish-bellied rails were laid down upon this railway with chairs, for which

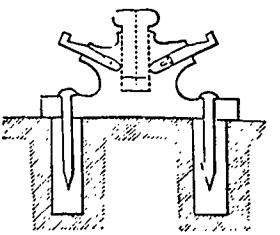


Fig. 2948. STEPHENSON'S PATENT.

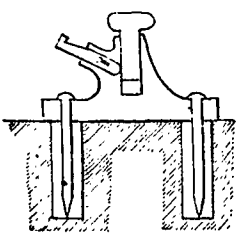


Fig. 2949.

Mr. Robert Stephenson took out a patent; the weight of the rail was 50 pounds per yard in length, and it fitted exactly into the chair, with no space for lateral movement. A key acts directly against the side of the rail through a mortise-hole passing into the sides of the chair; through these holes is driven a tapering key, which, acting upon the pin, forces it against the sides of the rail. The pin has a sharp point, and therefore, when tightly driven, indents itself into the rail.

On the London and Croydon Railway chairs are dispensed with altogether, and the rail is screwed down to longitudinal sleepers, laid on transverse timbers throughout. The base of the rail is in width $4\frac{1}{2}$ inches, producing great steadiness: in every yard in length are two sleepers, and over them four rows of longitudinal sleepers; 16,672 cubic feet of timber were used for every mile. The cross or transverse sleepers are 8 feet in length, and 9 by $4\frac{1}{2}$ inches; the longitudinal timbers 9 by $4\frac{1}{2}$ also.

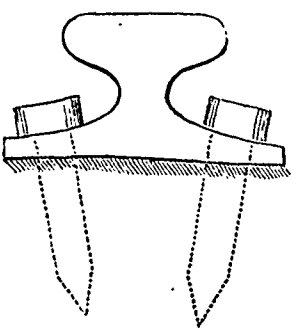


Fig. 2950.

The iron rails were in weight per lineal yard 48 pounds, and that per mile was 337,930 pounds; there are 7040 trenails, as many bolts, and 16 screws to every yard, making 28,160 screws,

weighing 4692 pounds. These materials, including the labour of fixing them, and the ballast over an average breadth of 26 feet to a depth of 18 inches, cost 5211*l.* 4*s.* per mile.

An iron rail of this form, resting on a continued sleeper, is considerably stronger than when placed on chairs; a 48-pound rail, so applied, is as strong as one of 75 pounds when resting on points of support 3 feet distant. The sleepers were all of Memel, and the screw-bolts, which secure the rails, were 18 inches apart.

Helton Rail has a half lap joint; the bottom of the chair is let into the stone and secured by two wooden pins; a convex boss is cast in the bottom of the chair, upon which the

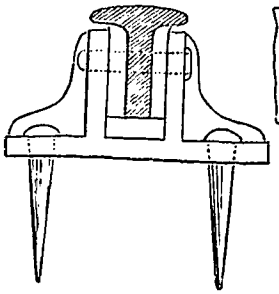


Fig. 2951.

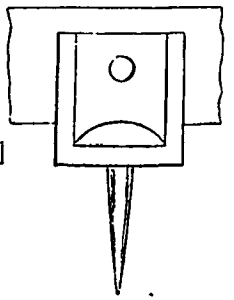


Fig. 2952.

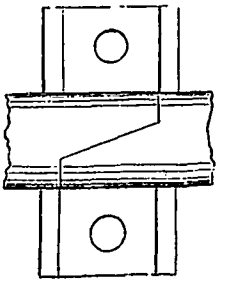


Fig. 2953.

ends of the rails are halved, and a pin, passing through a hole cast in them, secures them to the chairs.

The Southampton Railway bars are of a parallel form, and weigh 75 pounds per lineal yard: they were placed in two varieties of chairs, the weights of which were 26 and 22 pounds. The rails are in lengths of 15 feet, their depth is 5 inches, the width of the tops and bottoms $2\frac{3}{4}$ inches, and the thickness of the middle $\frac{13}{20}$ of an inch.

London and Greenwich Rails are laid to a gauge of 4 feet $8\frac{1}{2}$ inches, and are of the edge form, $2\frac{1}{8}$ inches wide at top, $4\frac{1}{4}$ inches in depth, and 1 inch in thickness at bottom: they are supported in cast-iron chairs placed at distances of 3 feet. The chairs are fixed in rough blocks of granite or Bramley Fall stone, each containing about 4 cube feet.

Railway Curves. — When circumstances oblige a departure from the straight line, the curvature to be given to the rails is a point of the highest importance; if it be struck from a radius of $\frac{3}{4}$ mile only, the inclination of the rail rises but 16 feet in the mile, and the speed of the locomotive engine is reduced nearly on -half; but when the rails are perfectly level, the curvature does not materially impede the progress of the carriages. The flanges of the wheels on the outside rails of the curve, acting against the rails, prevent the carriages being thrown off; but to make them travel along the curve without friction, the wheels have the outside of their rims made conical, or their diameter is increased on the side next the flange. When the carriages move around a curve the wheels eing connected together form conical rollers, moving upon the rails with different radii, the smallest being that of the inner curve, and the increase of that diameter of the wheel which runs on the outer curve makes up to a certain degree for its increased length. The diameter of the wheels next the flange is generally 1 inch more than on the outside of the tire: the breadth is $3\frac{1}{2}$ inches; when moving in a straight line, they are usually placed upon the axle, so that they work at about 1 inch from the rail, but some latitude is allowed for their changing into a curved direction; and it is found that for 3 feet wheels, this kind of tire is quite efficient in preventing their rubbing against the inside of the rails at all ordinary curves.

When a carriage moves round a curve, its tendency will be to move in the direction of a tangent to that curve, which is altered by the force or velocity, as well as by the radius of curvature. By raising the outside rail, an inclination may be given to the axles, which will produce upon the carriages a gravitating force towards the centre of the curve, equal to the outward centrifugal force, and there will consequently be no extra pressure against the rail, nor any chance of the carriages being thrown off.

Turn-Tables only admit of one or two carriages being turned at the same time, and consequently are not generally useful; there is some trouble attending their management, and they require great attention. The length of the locomotives employed on the line determines their diameter: those on the London and Birmingham Railway are 12 feet, those on the Leeds and Selby 8 feet; they are made of cast-iron, and turn on a pivot in the centre; on the outer rim are rollers, which facilitate the rotary motion: that on the London and Birmingham line has 8 cast-iron rollers, 10 inches in diameter, working upon iron arms, which radiate from a wrought-iron hoop that works round the centre pivot. A circular ring of cast-iron, 12 feet 7 inches in diameter, surrounds the turning-table, and is in depth 1 foot 9 inches; at the bottom is a circular iron plate, 12 inches wide,

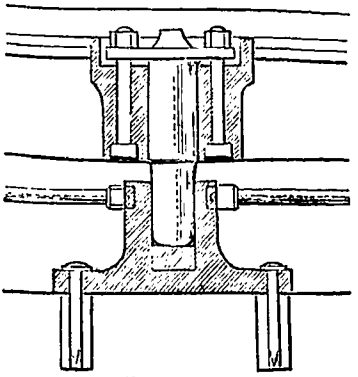


Fig. 2954.

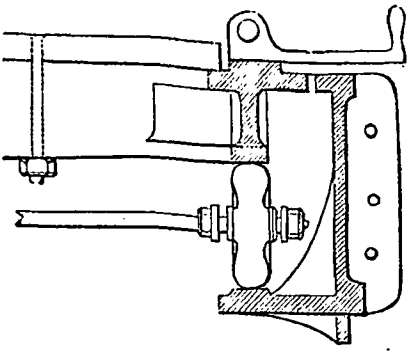


Fig. 2955. TURN-RAIL.

and 1¼ inch in thickness, upon which the rollers work.

The table rests upon four iron bearers at right angles with each other: they are 9 inches in depth at the middle, and 6¾ at the ends; their intersection leaves a square in the middle, the sides of which are 4 feet; from the angles of this square are four other arms serving as radii, which unite with the iron hoop that works round the centre pivot; they are 8¼ inches in depth at their junction with the hoop. The bearers are at the same distance apart as the rails on the line, and have holes ¾ inch in diameter cast in them, for the purpose of attaching the rails to the table; at their extremity is a circular cast-iron plate, which works round upon eight rollers; its width is 2 inches, and the distance from its middle to the centre 5 feet 1¾ inch.

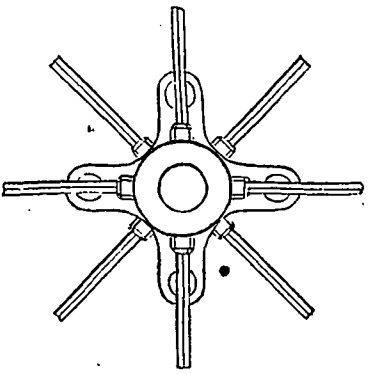


Fig. 2956. TURN-TABLE.

The rollers work between two wrought-iron hoops, 2 inches deep and ⅝ thick, and upon the ends of eight wrought-iron rods, ¾ inch in diameter, which are screwed into the hoop that surrounds and traverses the centre pivot. The hoop is also of wrought-iron, 1 inch in thickness, 2 inches in depth, and 5 inches in diameter, and is accurately turned, so as to work round the collar of the centre pedestal, which is also turned, and of cast-iron, with a hole 3 inches in diameter and 5 inches in depth, at the bottom of which is a brass step 2 inches thick, for the pivot to work upon. The pedestal is fastened to the stone block by four pins, and a hole is left for the necessary supply of oil to the pivot: to this pivot the table is attached by four screw-bolts, 1¼ inch diameter, so adjusted that by turning them it may be eased off, or lowered on the rollers. On the surface of the table two lines of railways are fixed at right angles, the rails being of wrought-iron, 3 inches broad and 2 inches thick, bolted to the principal arms with ¾-inch screw-bolts, their heads being counter-sunk into the rails. At the intersection of the rails are four sets of wrought-iron inclined planes, for the flanges of the wheels to run upon when passing the openings; and on the outer rim is a latch to hold the table in its desired position. Cast-iron gratings, ¾ inch in thickness, are made for the separate compartments, and put into rebates formed to receive them.

Passing from one Line of Railway to another.—Where double lines of railway are laid down, and carriages of equal speed run upon them in opposite directions, the necessity for turning out, or for sidings to allow them to pass, is avoided: but where there are

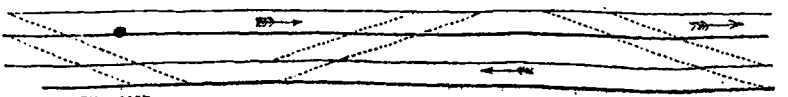


Fig. 2957.

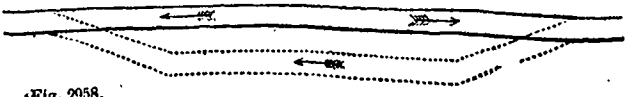


Fig. 2958.

two classes of carriages, one for passengers, and the other for goods, varying in speed, means must be provided to allow of their occasionally passing each other, without which the passengers' carriage would be subject to delay and obstruction from the one more heavily laden.

As there is always some risk in passing in and out of a line, it is advisable to have as few sidings as possible: in the best contrived crossings, trains rapidly passing may meet with accidents, if there be the slightest want of care and attention on the part of the attendants. Where there is a single line of railroad, either of the three methods shown may be adopted, as the carriages, travelling in either direction, can pass by the sidings without inconvenience to those going in an opposite direction. The first is generally applied when the carriages are all proceeding in the same direction, but

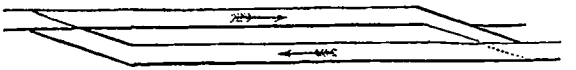


Fig. 2959.

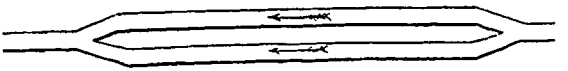


Fig. 2960.

Fig. 2961.

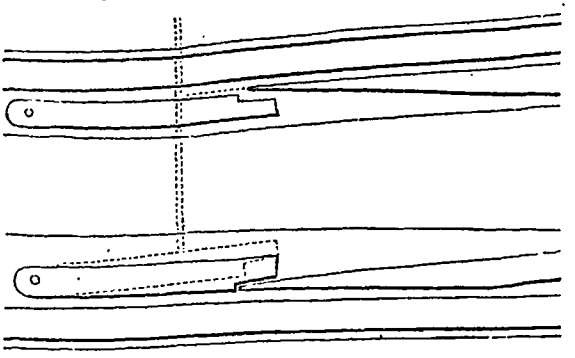


Fig. 2962.

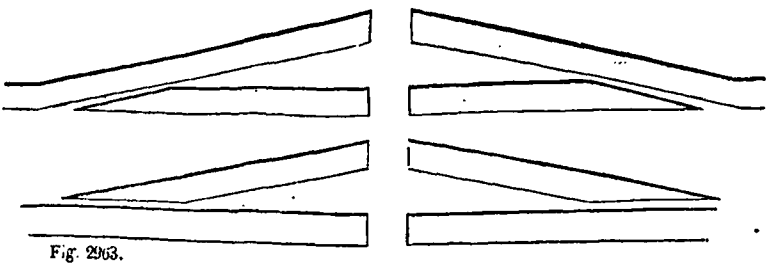


Fig. 2963.

with a difference in the speed, a movable rail is alone required to divert them into the siding, or a switch which is restored to its first position by the servant whose business it is to attend it: should carriages require to pass in an opposite direction, the switches are moved so as to enable them to digress, and again enter the main line. Loaded carriages invariably keep the line, and the empty ones take the sidings, the movable rail being on the side towards which they pass.

In the second example, the movable switch is dispensed with, as the carriages can pass each other without changing the rail: this arrangement is usually adopted in mines. The third example allows the carriages both going and coming to diverge, and the main line to be gained by both. Wherever the sidings are adopted, the oblique lines of rails should be laid at an angle that will prevent the carriages passing by them from having their wheels thrown off the rails by the sudden change of direction, which angle must in some degree be determined by the speed: when this is not more than 8 miles an hour, it may be made at that number of degrees; but when at 20 or 30 miles 1½° or 2° should be the extent of the angle from the straight line.

Switches and their Movements.—The point and switch rails are most commonly used for sidings, and when worked by hand, they always remain open, so that if the trains are required to be moved into the siding place, this is effected by moving the switches: they are sometimes kept shut by the application of a weight, which the loaded carriages can push open, but the empty ones cannot, so that they are obliged to pass by the siding. The ends of the point rails do not touch the continued line, and the space left between them is

a great objection to rapid movement, carriages passing over it being subject to a shock, to remedy which inconvenience the rail is sometimes made to turn on a joint, so that the carriages can pass in a straight line, those coming in an opposite direction opening the inner rail on one side, and shutting the other by their own pressure.

For the switches on the Liverpool and Manchester Railway, about 9 feet of the rail on each side are moved on a cast-iron framing, securely bedded in the ground, or placed on chairs made to receive it: the moveable rails are united by an iron rod, and work upon a joint at one end. A horizontal sheave is fixed on a false centre, with an iron ring working round it in the manner of an eccentric, so that when the handle attached to the vertical rod is turned it will either open or shut the rail.

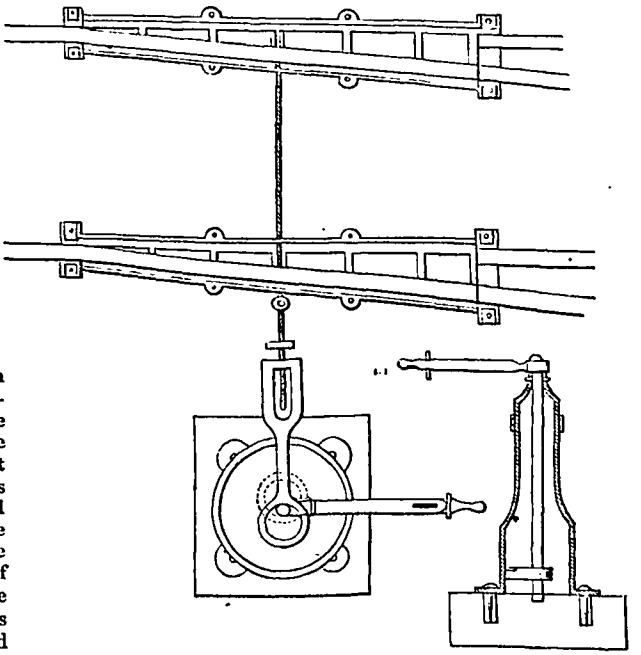


Fig. 2964. KILLINGWORTH RAILWAY. Fig. 2965.

In another system practised on this railway the rails are placed upon a frame of cast-iron; two short rails move on joints at their ends, and work to either side upon it; they are united by a bar of iron, and when in one position the carriages pass by the continued rails; when in the other they are diverted: these switches are moved in a similar manner to those already described on the same railway.

The most usual plan is the crossing-rail: to prevent the wheels running off, the top of the rails is sunk below the surface, but the openings, where they cross, subject the wheels to a shock in their passage; the flanges are on the inside of the rails, and where narrowed out to a mere point, they are liable to change of form and to get out of order.

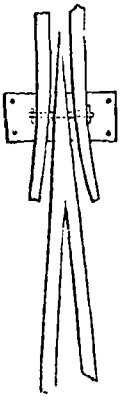


Fig. 2966.

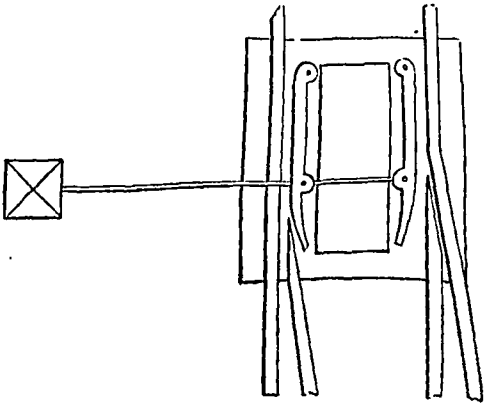


Fig. 2967.

Engine for a double Plane. — The shaft which turns the machinery, fig. 2968., may be moved by manual labour; but where a steam-engine is employed, a crank will be necessary, or the shaft may be attached to a water-wheel. The cylinders upon which the rope

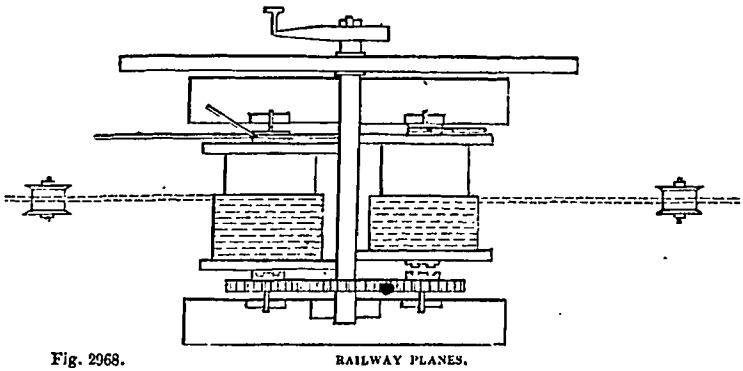


Fig. 2968. RAILWAY PLANES.

coils can be put out of gear by couplings, or by the ordinary methods of disengaging machinery; one end of the small levers in turning touches the cylinders, which drives them into the clutches fixed at the other end, and throws them out of gear. The fly-wheel which regulates the motion is made proportionate to the cylinder.

When there are a succession of planes throughout a railway, as is the case in some situations, it is necessary at the top of each pair of planes to have two rollers on which the rope coils, worked by a stationary steam-engine. Ropes attached to the carriages draw them up and let them down the inclined plane: each station must be provided with two rope rolls, one uncoiling at each end of the train. When it is required that the carriages should descend, the action must be reversed, enabling them to proceed in the opposite direction, or towards the roll at the further end of the train; thus, by an endless rope working alternately round a cylinder at each end of the railway, a regular transit is maintained. The ropes must always be placed in a line with their work, or the middle of the cylinders must be opposite the division of the rails.

Where a line of railway is to be worked by stationary engines, they are placed at regular distances, each engine drawing the carriage to it from the opposite end, unwinding at the same time a rope from the roll of the next engine, which in its turn pulls a carriage or train in the opposite direction, by re-winding the rope on its former cylinder.

When engines of great power are made use of, four trains of carriages may be drawn towards them by four rope rolls at the same time: on the Liverpool and Manchester line a fixed engine is employed to drag the waggons loaded with merchandise up an inclined plane of 1 in 22, for a length of 2250 yards: this is effected by an endless rope; at the summit of the plane is a horizontal wheel worked by a pair of engines, one on each side; the waggons always mounting by one road and descending by the other, so that they are in a right position for the locomotives which bring them, or are to continue them on their journey. In some instances a horizontal shaft extends across the whole width of the railway, upon which, in the middle of each pair of rails, is a wheel 20 feet in diameter with a groove on its vertical edge. The rope which ascends the plane is passed over the upper edge of the wheel, round the under side, and then nearly to the top a second time, by the aid of a sheeve 4 feet in diameter in front. The rope nearly surrounds the 20 feet wheel, and the adhesion is powerful enough to pull up 80 or 90 tons on a plane with a rise of 1 in 100.

Self-acting Planes.—It has not been determined at what angle a plane should be laid, that would give to a carriage passing it a regular and uniform motion: to produce this the motion should be greatest at the starting point, so that the body should descend by the law of gravity with accelerated force at first, and afterwards gradually lessen. The cycloidal curve has been adopted for this purpose, as giving a diminution of force at the termination proportionate to the gravity at starting; were the inclined plane regular in its descent, the force would accumulate with the body that descended it, and carriages placed upon it would increase their velocity when they were required to be at rest. At many of the mines the loaded carriages draw up the unloaded, and then two inclined planes are necessary; but it is exceedingly difficult to decide on the angle at which they should be laid, as it must greatly depend on its uses and the weights to be drawn, as well as time allowed for the transit.

CHAP. XXXI.

PRINCIPLES OF PROPORTION.

FOR a full and comprehensive view of architecture, we must refer the reader to the Encyclopædia on that subject so ably written and illustrated by my friend Mr. Joseph Gwilt, and confine our attention to the principles and science of building, the more immediate province of the civil engineer. "Architecture," says Vitruvius, "has for its parents practice and theory; the first is the result of the frequent and continued contemplation of the mode of executing any given work, or the operation of the hands for the conversion of the material in the readiest way: theory is the reasoning produced by that contemplation, demonstrating and explaining that the material wrought answers the end proposed, and on him alone who is familiar with both branches of the art can the title of architect be justly bestowed; the theory, however, may be studied by all, but the results of practice can only be fully appreciated by the practitioner; and the civil engineer should not only be acquainted with all the sciences, of which an epitome has now been presented to him, but have a thorough knowledge of the principles of architecture, and the character of each particular style; but that branch which is most intimately connected with his practice, the proportioning of masses, or the arrangements for the supports of an edifice, must be the objects of his unwearied study and attention.

We shall therefore endeavour to point out, as briefly as possible, the general features which in this respect belong to the three great divisions, viz. the Greek, the Roman, and the architecture of the middle ages. That part of Greece which lies to the south of Thessaly, near the foot of Mount Othrys, is supposed to have contained the capital of Hellen, who left his kingdom to his three sons Æolus, Dorus, and Xuthus, the second son becoming the founder of the Dorian race, and the youngest that of the Ionian.

Architecture can hardly be said to have existed as a science until the Dorians perfected that style, which we find in the temples and other buildings scattered throughout those islands and countries in the Mediterranean Sea which received Doric colonies. The dwellings of these early civilisers of mankind were plain and simple; the laws of Lycurgus forbade the use of any carving or decoration, their doors being fashioned only with the saw, and their roofs by the axe; but in their temples and public edifices, they were encouraged to bestow more labour and superior workmanship: the Dorian architecture appears never to have undergone any great change; the same style, and almost the same proportions, are found in most of the examples that have been spared us.

These people spread a knowledge of the arts of construction wherever they settled; and we find them at a very early period in the northern districts of Greece, under the Olympian chain of mountains, in the island of Crete, on the eastern side of the northern coast, on which is situated the town of Cnossus with its harbours, Heracleum and Apollonia, at which latter places their religious rites were celebrated. After having overrun Thessaly, they sent from thence a colony to the district of Driopis, called the Doric Tripolis, between Œta and Parnassus, from the union of the three cities Bœum, Cytinium, and Erineus, and, subsequently, when Acyphas was added, Tetrapolis.

The country next occupied by the Doric tribes extended from the river Sperchius beyond Œta to Parnassus and Thermopylæ, but the most important of their migrations was that called the Return of the Heraclidæ. After this period they were for a short time driven into Attica, where they received protection from Theseus, and when again settled in the Peloponnesus, they sent out colonies to Rhodes, Cnidus, and Cos, led by princes of the Heraclidæ from Argos and Epidaurus. Another colony from Trœzen was established at Halicarnassus. The towns which composed the Tripolis of Rhodes, together with Cnidus, Cos, and Halicarnassus, formed the Doric league called Hexapolis, but after the separation of the latter place, Pentapolis: this league met on the Triapian promontory to celebrate the rites of Apollo and Ceres. A colony was sent from Lindos to Telos; others from Cos, Nisyrus and Calydna; from Argos to Carpathus, now the island of Scapanta; from Cnidus to Syme, a town of Asia Minor; from Megara a migration took place, which settled at Astypalea, one of the Cyclades; and others to Anaphe, Thera, Phalegandros, Melos, Myndus, Mylasa, Cryassa, Synnada, and Noricum in Phrygia.

The Rhodians founded Gagæ, and Corydalla in Lycia, on the shores of Asia Minor; Phaselis on the confines of that country; Pamphylia; and Soli in Cilicia. According to Thucydides, about 713 years before Christ, Antiphemus led a colony from Lindus, and founded the town of Gela in Sicily.

Corinth sent out numerous colonies from Lechæum in the Cresæan Gulf, which founded Syracuse about 760 years before Christ; Molycrion, Chalcis, towns of Æolia; Salicum in Acarnania; Ambracia and Anactorium in Epirus; Leucadia, now the island of St. Maura, which was formerly joined to the continent by a narrow isthmus; Coreyra, on the coast of Epirus; Epidamnus in Macedonia; Apollonia Potidæa, with several others.

Issa, an island in the Adriatic, was peopled from Syracuse. Megara, situated between Corinth and Athens on the Sinus Saronicus, after it became a part of the territory of the Heraclidæ, sent colonies to Astacus in Bithynia and Chalcedon, another city in that province opposite to Byzantium, Selymbria in Thrace, and Heraclea in Pontus, celebrated for its naval power.

Megara also colonised Hybla in Sicily, famous for its wild thyme and honey, which people founded Selnus. Sparta founded Tarentum about 700 years before Christ, which at one time comprised thirteen tributary cities within its government, and could muster 100,000 foot and 3000 horse.

From Gela, which was colonised from Lindus in the Island of Rhodes, originated Agrigentum, a place of considerable importance at the time the Cretan Phalaris obtained the sovereignty; indeed Crete and Rhodes jointly may be said to be the founders of Agrigentum.

In following the progress of the Heraclidæ along the shores of the Mediterranean to the Pillars of Hercules, we find wherever they settled those beautiful examples of construction in masonry which we can never be weary of admiring and studying. The temples in the Doric style in Sicily are of great beauty, and they may be some years anterior to those now remaining in Greece, but the difference cannot be very great: those at Syracuse and Agrigentum were constructed from the spoils obtained when Hiero defeated the Carthaginian general Hamilcar at Himera, and those at Athens were not built till some time after the defeat of Xerxes; but by some of the historians it is said that both battles were fought on the same day, that whilst Hiero was obtaining his independence, the Persians were overthrown at Salamis. Some time, however, elapsed after these victories before the Athenians and other states of Greece which had been engaged in the war recovered their prosperous condition; and it was not until the time of Pericles, which is nearly 50 years after the building of the temples at Agrigentum and Syracuse, that the restoration of the Parthenon and other public buildings throughout Greece was undertaken. The temples at Selinus are said to have been built when the city was founded, 620 years before Christ, and it is asserted they were entirely destroyed when the inhabitants deserted the city 250 years after its foundation: could this be proved, they would rank among the first erected.

The Propylea at Athens was built by Mnesicles in the 85th Olympiad; and a few years afterwards, when Pericles governed, Ictinus completed the Parthenon, and probably the temple of Theseus. The temples at Sunium and Phygalia were also the work of that renowned architect, and are deservedly ranked for their proportions and execution among the most graceful productions of Greek architecture. The temple of Jupiter Panhellenius in the Island of Egina was founded by Eacus before the Trojan war, but the ruins we now admire no doubt may be referred to the time of Pericles.

The source of those beautiful effects which have received the almost instinctive admiration of every age and country can only be traced by correct measurement, and a careful observation of the proportions of the masses, which will almost irresistibly convince us that in temples and fronts of porticoes one general law prevailed, and was applied to all tetrastyle, hexastyle, and octastyle arrangements, based upon the proportion of a cube. This is found to govern most of the designs executed from the time of Pericles to the death of Alexander, the golden age of Greek art, when sculptors, painters, architects, and engineers were called forth to vie with each other in their several branches, and workmen of skill and ingenuity were found to embody the suggestions of their imagination; and the results would lead us to suppose that the acmé of perfection was attained, for since that period none of the productions either in sculpture or architecture have equalled those of the Greeks in the simple elegance of their design, or the excellence of their execution.

Tetrastyle Porticoes with four columns exhibit the simplest, and perhaps the earliest, application of the Doric order; the entire façade is comprised within a square, the height being divided into three portions, the upper constituting the entablature, and the other two-thirds being divided equally between the supports and their three intercolumniations, making the latter a little more than a diameter. We may imagine the square divided in its height and width by 8, making altogether 64 compartments of equal area; the upper 8 devoted to the pediment will have, when the inclined sides are set out, a diminution of one-half their area, four whole squares being rejected in those parts above the pediment, the area of the tympanum being only equal to four. The entire mass is thus reduced to the area of 60 of these squares, which are thus disposed of; 20 are given to the supports, or 5 cubes to each column, 20 are divided between the three intercolumniations, and the remaining 20 constitute the load supported; the columns are 5 diameters in height, and bear no more than their own weight, a due harmony being obtained through-

out; the eye is satisfied that the load cannot distress its supports, and the spaces between the supporting masses are again proportioned and made equal to either, so that we have a triple division,—one, the perpendicular arrangements of the supports, another their just distribution or equal distances, and the third, the entablature proportioned to the strength that is to carry it, all of which are comprised within the boundary of a square. The tetrastyle porticoes that remain are not numerous, and none are perfect; three have been selected, which will enable us to test the idea we have attempted to define. First, that at Eleusis, the entire width of which is 20 feet 6 inches, the height 21 feet 6 inches; and if we reject half the height of the pediment we shall have a square: the united diameter of the columns only varies 5 inches in width from those of the intercolumniations.

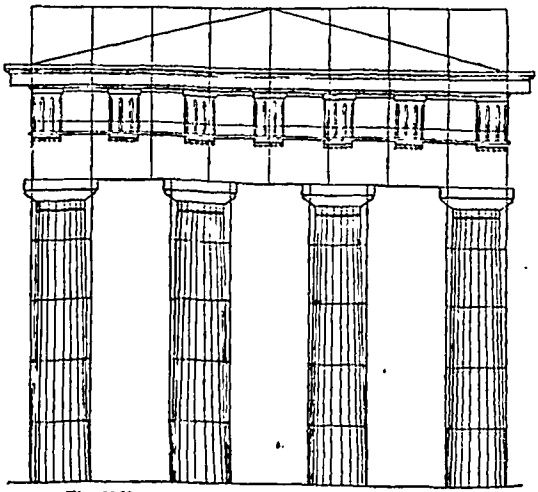


Fig. 2969. TETRASTYLE PORTICOES.

If we divide the height into three, rejecting, as already observed, half the pediment, which in this case is 1 foot $1\frac{1}{2}$ inch, we have for the height of the square 20 feet 4 inches, whilst the entire width is 20 feet 6 inches, a difference not very great: this divided into three, and giving two-thirds to the height of the columns, would make them only 13 feet 6 inches and 8 seconds, whilst they really are 14 feet $2\frac{1}{2}$ inches in height. In this example the entire height, which we may call 21 feet $5\frac{1}{2}$ inches, is divided into three, two parts of which constitute the height of the columns.

In the Temple of Themis at Rhamnus, the width is 20 feet 11 inches, and the height the same, the diameters of the columns being in excess 3 inches only above the width of the intercolumniations.

In the Doric Portico at Athens, the entire height equals nearly the width.

Hexastyle Porticoes. — The practice of the Dorian architects, in setting out a temple with six columns in front, appears sometimes to have been to divide the width into twelve parts, the height without the pediment being made equal to eight of them; thus forming a façade within a parallelogram or a square and a half: as the ninth division in height cuts the pediment in half, we have thirty-six squares for the entablature or mass supported, being the same quantity found in the six columns and the five intercolumniations; at other times we find the entire width divided into nine parts, and six given to the height, one of which indicates the pediment, thus rising a ninth: if a circle be described in the tympanum, and a horizontal line drawn through the centre, cutting off a twelfth of the height, the remaining $\frac{11}{12}$ being divided into three equal parts, the upper third, or entablature, being the part supported, the remaining $\frac{2}{3}$ are divided between the columns and their interspaces; thus making the columns equal to $\frac{2}{3}$ of the height comprised between the centre of the tympanum and the platform upon which they were placed.

If we take each of these nine parts as 5 feet, we have 45 feet for the width, 30 for the height, including the 5 feet for the rise of the pediment, which if we divide by the horizontal line, to obtain its true area or quantity, we shall have 2 feet 6 inches for its mean height, and 6 feet 8 inches for that of the level entablature: for as we have observed, these two dimensions, which make 9 feet 2 inches, must be equal to half the height of the columns, or the whole will not be divided into three parts; or, which is the same thing, the height from the centre of the pediment must be divided into three parts, and the upper division taken for the entablature. These proportions are exceedingly simple in their application; if it were intended that the columns and the spaces between them should be equal, half the width of the façade, or 22 feet 6 inches, should be distributed among the intercolumniations, and the other half divided among the columns.

The Temple of Theseus at Athens is one of the best preserved as well as the most admired, and was probably erected soon after the Parthenon; it is of Pentelican marble, adorned with admirable sculptures. The total width of its hexastyle portico is 45 feet, and its height, instead of 30, is 31 feet; the extra foot, which prevents it being an exact square and a half, is given to the pediment, which probably has undergone some change, as it rises much more than the ninth of its whole extent.

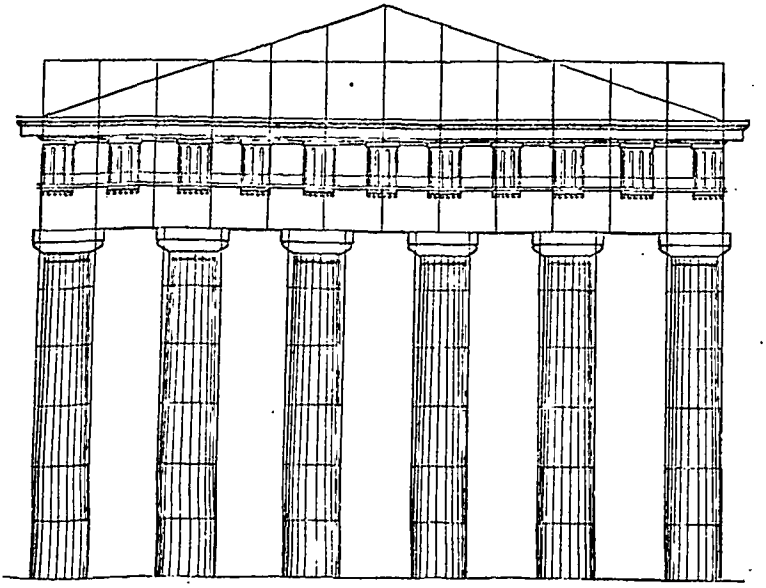


Fig. 2970. HEXASTYLE PORTICOES.

	Feet.	In.
The height of the pediment is	5	9·75
level cornice	1	0·45
frieze	2	8·55
architrave	2	8·9
columns	18	8·8
and of the entire façade	31	0·45

	Feet.	In.	
half the pediment	2	10·875	
the level entablature	6	5·9	
making together a dimension nearly equal to half the height of the columns.			9 4·775

The façade of this beautiful temple is divided equally into three parts; $\frac{1}{3}$ is given to the entablature, and the other two to the columns and their intercolumniations. The outer columns are 3 feet 4·85 inches in diameter, and all the others 3 feet 3·4 inches. The middle intercolumniation is 5 feet 3·95 inches, the next two each 5 feet 4·05 inches, and those towards the angles 4 feet 6·35 inches. The diameters taken together are 20 feet, and the intercolumniations 25 feet, so that the columns and their spaces are not in equal proportions: the former would have required a diameter of 3 feet 9 inches, which would have made them nearly five diameters in height, instead of what they are; they would have been heavier, it is true, but more in accordance with the early examples.

The Hexastyle Temples at Rhamnus, Sunium, Egina, Eleusis, and Phygalia, are not sufficiently perfect to enable us to decide whether our principles would apply to them: but from the judgment we can form from their remains, they appear to have been all comprised in a square and a half, and their entablatures and pediments in the proportion of a third of the whole.

The Hexastyle Temple at Segesta in Sicily is sufficiently perfect to enable us to judge of its entire proportions.

	Feet.	In.
Its total length is	76	0
and height	50	8

or the whole façade is bounded by a square and a half.

	Feet.	In.
The height of the columns is	31	0
entablature	11	4
pediment	8	4
Total	50	8

	Feet.	In.
Half the height of the pediment is	4	2
entablature	11	4
Total height of superincumbent mass	15	6

which is exactly one-half of 31 feet, the height of the columns; so that we have, as far as height is concerned, $\frac{1}{3}$ for the superincumbent mass or entablature, and $\frac{2}{3}$ for the columns and their intercolumniations.

	Feet.
The columns have their united diameters	37
The intercolumniations ditto	39

so that they are not in exact equality, although the difference is not considerable.

At Agrigentum are the remains of four Hexastyle Temples.—That of Juno Lucina is without its cornice and pediment: the diameter of the columns is 4 feet 6 inches, and the entire width is 55 feet. The united diameter of the six columns is 26, and of the five intercolumniations 29 feet.

The Temple of Concord is in width 57 feet, and in height 38; or it is comprised within a square and a half.

	Feet.	In.
The height of the columns is	23	0
entablature	8	0
pediment	7	0
	38	0

	Feet.	In
Half the height of the pediment is	3	6
The height of the entablature	8	0
which is equal to half the height of the column	11	6

Thus one-third of the entire height is given to the entablature or mass supported. The united diameter of the columns is 28 feet, and that of the intercolumniations 29 feet, the latter being a little in excess.

Temple of Hercules.—The total width is 84 feet, and height 56, which is a square and a half.

	Feet.	In.
The height of the columns is	33	6
entablature	13	0
pediment	9	6
Making a total height of	56	0

The united diameter of the columns is 43 feet, and that of the intercolumniations 41 feet. The height of the entablature and half pediment is in this case 17 feet 9 inches, instead of 16 feet 9 inches, as it should have been to have equalled half the height of the columns.

Temple of Castor and Pollux is imperfect, but the total width is 45 feet, of which the diameters of the six columns occupy 24 feet, and the intercolumniations 21. The height of the columns is about 20 feet, and that of the entablature 8 feet, as measured on the flank. This temple nearly agrees in width with the temple of Theseus at Athens, but its proportions vary; there is not sufficient remaining to judge of its entire form.

At Selinus are the remains of five hexastyle temples. In one the total extent is 51 feet, of which the united diameters of the columns occupy 24, and that of the five intercolumniations 27 feet. The height of the entablature is about 11 feet, but that of the columns and pediments has not been yet ascertained.

The second temple is in width 77 feet 6 inches, the diameters of the columns occupying 37 feet, and the five intercolumniations 40 feet 6 inches; the height is 50 feet 8 inches, so that the whole façade is included in a parallelogram, having a height not quite equal to two-thirds its extent, or a square and a half.

	Ft.	In.
The height of the columns is	29	4
entablature	13	4
pediment	8	0
In all	50	8

which is a foot less than the required height.

In this example there is not an exact correspondence between the columns and what they support: the entablature and pediment occupy 13, the intercolumniation 12, and the

columns 11 parts out of the whole number, 36, into which the parallelogram may be supposed to be divided.

The third temple is not sufficiently measured to enable us to examine into its proportions; the total width is 79 feet, of which the united diameters of the six columns occupy 36 feet, and the five intercolumniations 43 feet.

The fourth temple is in width 84 feet 9 inches, and in height 56 feet 6 inches or a square and a half.

	Feet.	In.
The height of the columns being	34	0
entablature	11	6
pediment	11	0
In all the height is	56	6

	Ft.	In.
The height of half the pediment is	5	6
the level entablature	11	6
Making a height equal to half that of the columns, viz.	17	0

Thus the heights are in just proportion, one-third being given to the entablature and pediment, and the other two-thirds to the columns and their intermediate spaces, which are in the proportions of 44 feet 9 inches for the columns, and 40 feet for the five intercolumniations.

The fifth temple is 81 feet in front, the six columns occupying 37 feet 8 inches, and the five intercolumniations 43 feet 4 inches. The height of the column is 31 feet, and the entablature 15 feet 6 inches, or one-half the height of the column, so that, without the pediment, the entablature in this example would constitute a third; and if the pediment had only risen 7 feet 6 inches, to make the general proportion a square and a half, these columns would have had more to sustain than any other example we have yet referred to.

Octastyle Temples.— We will now apply these principles to a façade with eight columns, and endeavour to follow the same system. We have already had a square, and a square and a half, as the form or figure within which the design was comprised; the portico of four columns being circumscribed by the one, and that of six by the other; and as in the octastyle there are double the number of columns contained in the first, a double square is required to comprise it, that the same relative proportions may be obtained.

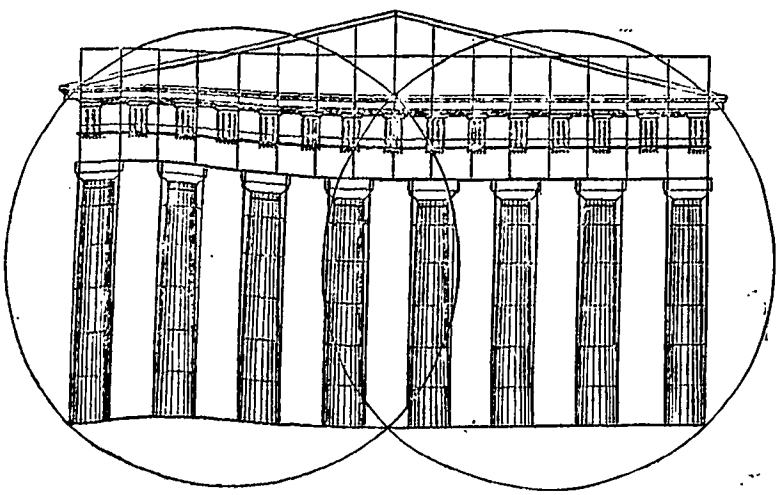


Fig. 2971. OCTASTYLE PORTICOES.

After the width of the façade is determined, it is divided into sixteen parts, and ten are set out for the height to the top of the tympanum of the pediment; which generally rising a ninth of the extent, two divisions will serve to denote it, and if a circle be inscribed in the tympanum, and a horizontal line drawn through the centre, we shall have a parallelogram 16 squares in width, and 9 in height.

Six squares in height will determine the under side of the entablature, which, if divided equally between the columns and their intercolumniations, would give 48 squares to each, which are precisely the proportions of the example we are about to examine.

' *The Parthenon or Temple of Minerva at Athens* is admitted to have the most beautiful proportions of all octastyle Greek examples;* its entire width, measured in the front of the columns at the base, is 100 feet 9 inches; and its height to the centre of the tympanum, from the level of the platform on which the columns are placed, 51 feet 2½ inches, 20 inches only beyond what it should be to accord with the rules laid down. Dividing this height into three parts, we have in round numbers 17 feet 1 inch for each: the height of the entablature and half pediment is 17 feet, and that of the columns 34 feet 2 inches, precisely one-third of the height being devoted to the entablature, the lower two-thirds being divided between these and their intercolumniations; adding all the diameters together, we have 49 feet 6 inches; the intercolumniations being 51 feet 3 inches, or only 1 foot 9 inches in excess for the latter: hence if a parallelogram or double square be divided into 40½ squares, and 13½ be given to the columns, the same quantities to the intercolumniations, the entablature and its pediment, we should have the general proportions of the Parthenon, the difference before alluded to being too slight to produce any effect on the eye in so large a mass. The height to the centre of the pediment is 51 feet 2½ inches, consequently the width to make it an exact double square should have been 102 feet 5 inches, instead of 100 feet 9 inches; and this difference may have been occasioned by the difficulty of setting out the triglyphs, or from the idea that the width, as measured along the corona, should have some consideration, and a mean be established.

As we have before observed that the Parthenon is considered perfect both in its design and execution, a more detailed account of its construction and mouldings will be the best illustration that can be offered on the subject of Greek masonry, premising that in the present instance it is all of the finest marble from Pentelicus.

The Doric Column varies considerably in its proportions, some not being more than four diameters in height, whilst in other examples they are from that to six and a half: those we are now considering are formed of twelve blocks; on the upper and lower bed of each are described two circles, the circumference of the outer being 9 inches from the edge, whilst the inner circle is only 20 inches in diameter. The space between these is not polished, but left rough as from the chisel, and a little sunk for the purpose of retaining

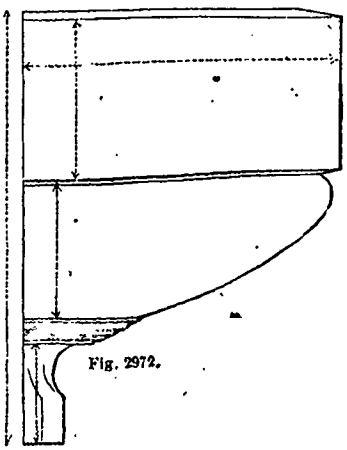


Fig. 2972.

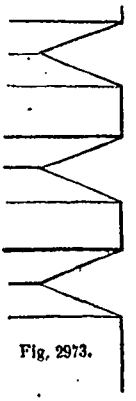


Fig. 2973.

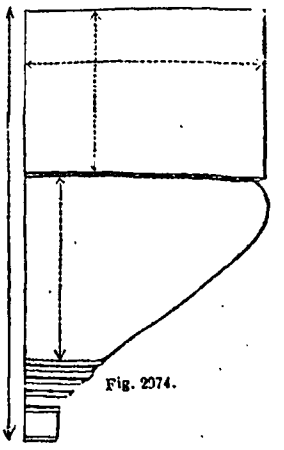


Fig. 2974.

ORIC CAPITALS.

a fine mortar or cement. In the centre of each block is a square hole, measuring 5½ inches on each side, sunk 3 inches in depth; in these were inserted pieces of hard wood, 6 inches in length, to steady the blocks, and keep them from being displaced, particularly at the time the flutes were worked, or the exterior was undergoing the process of polishing. The outer columns are 6 feet $3\frac{6}{10}$ inches in diameter at bottom, and the others 6 feet $1\frac{8}{10}$ inch, the upper diameter of the latter being 4 feet 9¾ inches: their total height is 34 feet $2\frac{8}{10}$ inches, or nearly five diameters and a half; the diminution is not regular, there being at a certain height a swelling or entasis, which improves the outline, and destroys that meagreness which is the result of a straight line. The angular column is a little more in diameter, that it may not appear less than the others, which are not so surrounded by air.

The shafts have generally twenty flutes, uniting in an arris, and not with a square fillet between them, as in the other orders; they are elliptical in some examples, as at Pæstum, where their number is 16 and 24; the heads are variously finished. The capital of this order varies in its height from ⅛ to ⅜ of the lower diameter of the columns, and the

abacus is sometimes more than ¼ longer than that width, all these proportions depending more upon the height of the column than upon its lower diameter.

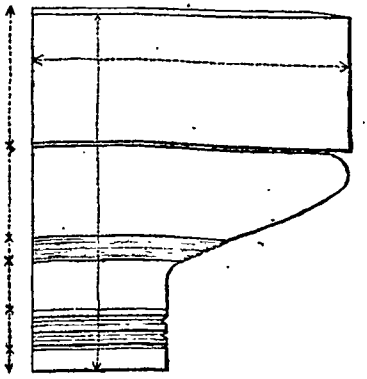


Fig. 2975.

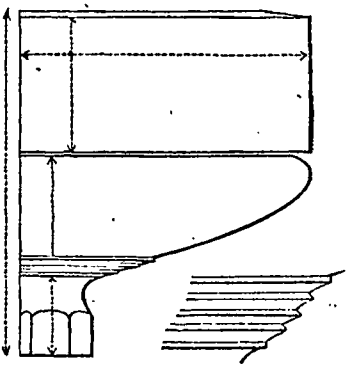


Fig. 2976.

Under the abacus is the *echinus* or *ovolo*, which is beautifully turned, or cut like the bell or profile of a flat cup, under which are usually from 3 to 5 annulets. The contour

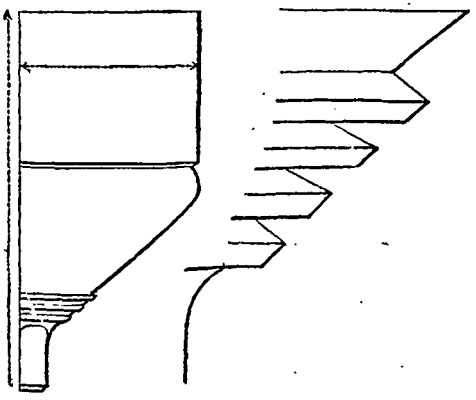


Fig. 2977. DORIC CAPITALS.

Fig. 2978. ANNULETS.

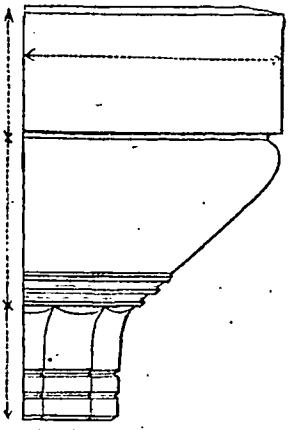


Fig. 2979. DORIC CAPITALS.

or profile of the echinus is a portion of a curve formed by the section of a cone. Where the capital is placed on the column is another sinking, and sometimes three; and the true and delicate manner in which these lines are cut gives a charm that more elaborate sculpture fails in attaining.

The architrave of the Parthenon, which extends from the centre of one column to that of the other, is in three thicknesses, showing two joints on the soffite. The frieze is admirably contrived not to overload the architrave: the triglyphs are each in a single block, 3 feet wide and 2 feet 3 inches in thickness. On each side is a perpendicular groove 1¼ inch deep, into which the sculptured metopes are slipped, the clear width between the triglyphs being 4 feet $3\frac{15}{100}$ inches, and the angular one 3 inches less: at the back of the metopes, and between the triglyphs, is a hollow space, from 8 to 14 inches deep. The metope is held to the back of the frieze by a metal cramp in the form of an H, 2 feet long, and attached on each side to the adjoining triglyph by others 17 inches in length. The cornice is in one thickness; the angular block covers two mutules, each of the others one space and a mutule. For further particulars of the construction of the Parthenon, and for several dimensions omitted by Stuart, the writer must refer to some notes he added a few years after his return from Athens to his wife's translation of "The Lives of celebrated Architects, ancient and modern, by Francesco Milizia."

In the Doric Order we may trace a reason for the direction given to the several lines, whether perpendicular or horizontal; and although there is great variety in the form of the members, yet when examined in detail, nothing will be found to disturb the unity

of the design. The voids are nicely adjusted to the solids, and all those parts, as the columns and triglyphs, intended as supports, are striated perpendicularly, whilst those supported are decorated with members and mouldings running horizontally, and indicating rest or repose. The inclined lines of the pediment are the only exception to this rule, and they are composed of longitudinal members, placed consistently with their use, viz. that of throwing off the water from the roof: so well-combined a whole, consisting of parts all expressing their utility, deserves our admiration: even the annulets under the echinus of the capital indicate so many cinctures to bind the tops of the perpendicular flutes together, before the elegant tazza or cup-like vase is placed between the shaft and the abacus.

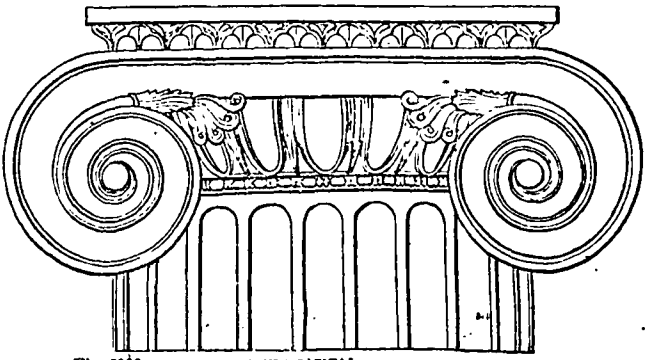


Fig. 2980. IONIC CAPITAL.

Ionic Proportions.—This style seems very nearly coeval with the Doric: it is supposed by some commentators to be of Achaic origin, by others of Persian; both Greeks and Persians may have contributed to its formation; the term Ionic was applied to it by Vitruvius, from its being first used by the inhabitants of Ionia; the few perfect examples remaining are of the greatest beauty, both in design and execution.

The shores of Asia Minor, in the reign of Medon, the son of Codrus, were taken possession of by a number of Greeks, who commenced their migration about a thousand years before Christ; after they had passed from Attica, they first mixed with the inhabitants of Caria and the Leleges. Helen the son of Deucalion, who reigned in Phthia, situated between the rivers Peneus and Asopus, having left his kingdom to his eldest son, the others sought for settlements elsewhere: Dorus established himself in the neighbourhood of Parnassus and Xuthus in Attica, where he married the daughter of Erechtheus, the sovereign of Athens, and had by her two sons Achæus and Io.

Io with a number of followers from Athens went into the Peloponnesus and established himself at Ægialus, a place on the sea-shore lying between Elis and Sicyonia; here he married the daughter of Selinuntus, king of that district, at whose death he succeeded to his dominions; Io built Helice, and called the inhabitants Ionians. Some time after Io was recalled to Athens to command the troops in a war against the Thracians, over whom he obtained a victory: the Athenians in consequence designated themselves Ionians. Attica was divided by Io among four tribes, the Geleontes, the Argades, the Ægicores, and the Hopletes, the names of his four sons, or according to Strabo, labourers, artisans, priests, and guards.

When Erechtheus died, Cecrops, his eldest son, succeeded, and Xuthus, his other son, was driven out of Attica; in the country he afterwards inhabited he built four towns, Œnoe, Marathon, Probalinthus, and Tricorythus, after which he died at Ægialus; his son Achæus then passed into Laconia and Thessaly, when he recovered his father's dominions; his two sons Archandar and Architeles went into Argos, where they married two daughters of Danaus, one of the royal family of Argos. The Lacedæmonians and Ægeans were called after Achæus Achæans, until the return of the Heraclidæ, when they were driven out, and obliged to flee to Ægialus and into Attica, where the Ionians again received them on account of their common origin.

At the death of Codrus, his youngest son Nileus embarked with all the Ionians into Asia, where they occupied eight of the Ionian cities, viz. Miletus, Ephesus, Myus, Teos, Priene, Lebedos, Erythræ, and Clazomene; the other four founded by the Ionians were Colophon, Phocæa, Samos, and Chios. The Ionians formed themselves into twelve states, because, according to Herodotus, they were previously so divided in the Peloponnesus; the names of the cities from whence they were ejected were Pellene near Sicyon, Ægira and Ægæ, Bura, Helice, Ægium, Rypæ, Patræ, Pharæ, Olenus, Dyme and Tritæa, the last being an island.

The inhabitants of Athens who migrated from the Prytaneum were the most noble

among the Ionians, though all who celebrated the Aplurian festival, from which alone the Ephesian and Colophonians were excluded, were afterwards called Ionians.

The appellations Doric, Ionic, and Corinthian are derived from Vitruvius: but it appears doubtful whether these terms were current among the Greeks: that author asserts that the first is the most ancient; "for Dorus, the son of Hellen, and the nymph Orseis, built the temple of Juno at Argos of this order when he reigned over the whole of Achaia and Peloponnesus: that many temples afterwards erected throughout Greece were of the Doric order, but by command of the Delphic oracle in a general assembly of the different states of Greece, thirteen colonies were sent into Asia, who built the cities before mentioned, and erected temples; among the first they dedicated was one to Apollo Panionios, having Doric proportions, and another to Diana, in which some variations was made. The first was of a masculine proportion, the other feminine, and the latter was the invention of the Ionian settlers, and afterwards called from them Ionic.

But if it be difficult to trace the Ionic order to its origin, we may analyse its proportions, and compare them with that order which prevailed so universally in Greece, which will lead us to remark that a very great change took place when the rules that guided the Doric builders were laid aside: at no other period were such material alterations made in the proportions of the masses, the columns, entablatures, and intercolumniations; to the Corinthian, so universally used in later times by the Romans, the feminine proportions were applied which are stated by Vitruvius to have commenced with the Ionians.

There is of course much fable in all the accounts that have reached us upon these important changes, but among them is one which seems to carry with it some semblance of truth, and which is as follows:—"when Hermogenes was employed to erect the temple of Bacchus at Teos, according to Vitruvius, the marble was prepared for one in the Doric style; but the architect changed his mind, from the idea that other proportions, afterwards called Ionic, were more suitable for the purpose, almost inducing the inference that Hermogenes was the inventor of those delicate proportions; he appears unquestionably to have displayed great skill and ingenuity in all his designs, and to have entertained the opinion that sacred buildings should not be constructed with Doric proportions, as they obliged the adoption of false and incongruous arrangements."

To obtain more delicate proportions, without sacrificing the great principle of making the weight supported equal to its supports, would seem at first difficult: in the example of the Doric order we have seen this practice universally adopted, and it is equally evident in the Ionic, though not exactly after the same method; the columns and their entablatures, or what they carry, agree in quantity, but their distribution is different. The square or figure which bounds the Ionic façade is divided into four parts, one of which is given to the entablature, a second to the columns, and the other two, or one half, are distributed among the intercolumniations.

In the quantity of material for constructing the two varieties of temples there is a considerable difference, the Doric requiring one-third more than the Ionic; for example, in a Doric tetrastyle portico where the area was 12, four parts would be given to the entablature, four to the columns, and four to the intercolumniations. In the Ionic three parts would be required for the entablatures, and three for the columns, six being allowed for the intercolumniations; thus one temple would have eight, and the other six parts solid out of twelve; consequently, with a given quantity of materials, two very different porticoes might be built, without making any change in the proportions which the columns bear to their entablatures. Hermogenes could construct with the same material a much larger temple in the Ionic style than in the Doric; and supposing the dimensions already decided upon, there would be a saving of labour and material: from the imperfect state of the Ionic temples remaining, it is scarcely possible to enter into a thorough examination of their proportions; that on the Ilissus at Athens, measured by Stuart, no longer exists, but its dimensions, given by that very accurate delineator, may serve our purpose as an example of a tetrastyle portico. Its entire width was 18 feet 7¾ inches, and height to the top of the level cornice in front 18 feet 4¾ inches, to which must be added that of the tympanum of the pediment: multiplying the width by the height of the entablature and half the pediment, which together is 5 feet 7 inches and 10 parts, we have for the area of the portions supported 105 feet 4 inches and 9 parts: the quantity contained in the four columns is found by multiplying their united diameters, 7 feet 1 inch and 7 parts, with their height, 14 feet 9 inches and 4 parts, giving a product of 105 feet 4 inches and 9 parts as their area. The united intercolumniations in this example are 11 feet 6 inches and 2 parts, which multiplied by the height of the columns is 170 feet 1 inch and 9 parts for the area; 40 feet 7 inches and 9 parts less than it would have been had it equalled the quantity contained in the columns and their entablature, or been one-half the entire area of the façade.

The portico of this elegant example of Ionic was nearly a square without the pediment, and the supports and supported are in exact accordance as to quantity, whilst the intercolumniations are about 1¾ times the quantity contained in the columns, instead of double. Departing a little from the proportions before us, let us endeavour to set out a

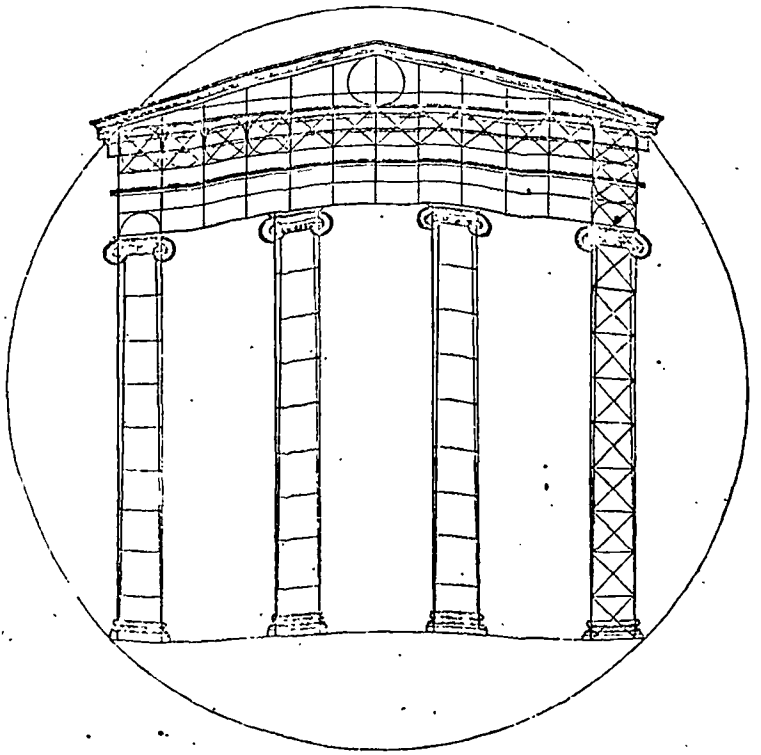


Fig. 2981. IONIC TETRASTYLE TEMPLES.

portico, as already done for the Doric order, having the same number of columns, and like the tetrastyle eustyle of Vitruvius, divide each side of the square which circumscribes it into 11½ parts, premising that the pediment rises a ninth and one side of the square passes through its centre. The side of the square being divided into 11½ parts, 1 is given to the diameter of the columns, 3 parts to the middle intercolumniation, and 2¼ to each of the others; thus the sites for the columns are obtained: dividing the upright sides of the square into the same number of parts, 8½ are given to the height of the column, and the remaining 3 to the entablature and half pediment.

Multiplying 11½ by the same, we have for the entire area 132¼, which if divided into 4 is 33 and a fraction for the columns, the same for the entablatures, and double that for the intercolumniations: the columns being four in number and 8½ diameters in height, their area will be 34 parts; the intercolumniations being 7½ in their united width, that multiplied by 8½, their height, gives 63¾ for their area, and the entablature being 3 high and 11½ in width, we have for its contents 34½ parts, giving a result of nearly a fourth for the entablature as well as for the columns, and a half for the intercolumniations. By making some allowance for the diminution of the columns, an exact agreement between the quantities might be obtained; those in the intercolumniations would then be found equal to those in the entablature and its supports, or half the entire square devoted to solid and the other half to voids: had the columns of the temple on the Ilissus been about 1 inch less in diameter, its proportions would have been in close accordance with those of the figure, where the 4 columns occupy 38 squares, the entablature the same number, and the intercolumniations 76.

Ionic Hexastyle. Temple of Erechtheus at Athens.—This highly-enriched example, executed in the finest marble, is in height without the pediment 26 feet 6¾ inches, and in width, measured along the front of the corona, 40 feet 6 inches, so that this portion is comprised within a square and a half or nearly so: the lower diameter of the columns is 2 feet $3\frac{8}{10}$ inches, and the upper 1 foot $11\frac{8}{10}$ inches, giving a mean of 2 feet $1\frac{8}{10}$ inches; their collected diameters are 12 feet 9 inches, whilst that of the intercolumniations at the same level is 23 feet $1\frac{6}{10}$ inches, nearly double the space occupied by the columns. The height of the entablature without the pediment is 4 feet 11½ inches, and its superficial content on the face 190 feet, and adding 85 feet for the area of the tympanum, we have altogether 275 feet,

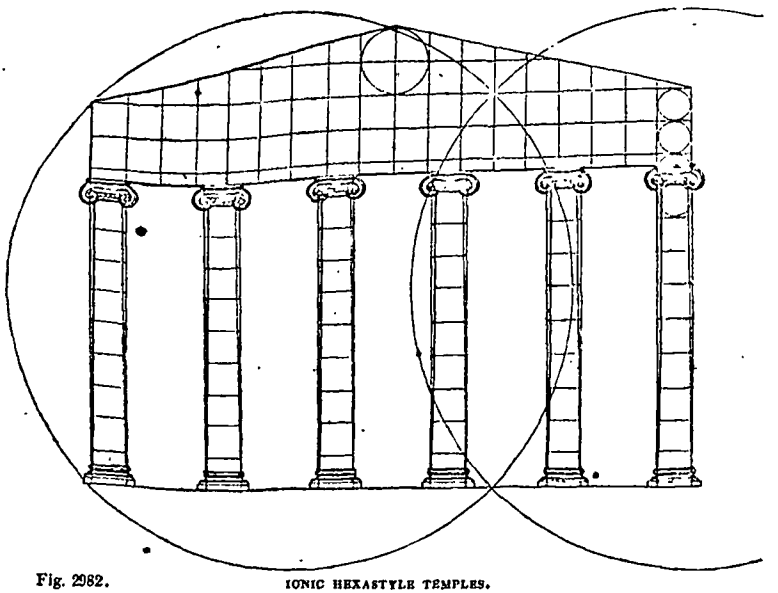


Fig. 2082. IONIC HEXASTYLE TEMPLES.

supposing the tympanum to rise a ninth of its base; the height of the columns is 21 feet 7½ inches, and their united mean diameter 12 feet 9 inches, which being multiplied together produce 275 feet 8 inches, or nearly equivalent to the area of the mass they support. To obtain the exact quantity of mass and void, the mean diameters of the columns as well as of the intercolumniations should be taken; the greater the probable delicacy of execution, the greater is the necessity for the architect to balance his quantities exactly. In the subject now under consideration the whole is comprised within a square and a half; the supports and the entablature are equal, and the intercolumniations as much as the two together or one-half the whole. The height of the architrave is 2 feet $1\frac{8}{100}$ inches; that of the frieze 1 foot 11¾ inches, and the level part of the cornice $10\frac{45}{100}$ inches.

Roman Tetrastyle. Ionic Temple of Fortuna Virilis.—The width is 33 feet 6 inches, and height, including half the pediment, 37 feet 1 inch, comprising an area of 1242 feet 4 inches, one quarter of which, 313 feet 1 inch, nearly agrees with the quantity contained in the entablature as well as in the columns which support it; their height is 27 feet, and their united diameters 12 feet 4 inches, which multiplied together produce 333 feet for the area of the supports. The height of the entablature with half the pediment is 10 feet 1 inch: this multiplied by its width, 33 feet 6 inches, gives 337 feet 10 inches for the area of that supported: the intercolumniations are together 21 feet 2 inches, which multiplied by their height, 27 feet, gives 571 feet 6 inches for their area, about 100 feet less than the quantity comprised in the columns and entablature.

Without the pediment this façade is nearly square; its proportions rank very high in the estimation of all admirers of Roman architecture; it has, however, undergone many reparations before the stucco was put upon the columns; they were lighter, as was the entablature, the upper members of the cornice being somewhat heavier than is usual in the early examples of this order; if divested of these additions, and giving a trifle more to the intercolumniations, we shall obtain half the area for the columns, and a quarter for each of the other divisions; at present the columns equal in quantity the mass they carry.

If it be required to draw a tetrastyle portico in exact accordance with the rules laid down, after forming the square each side should be divided into 12 parts, or 144 squares, arranged like those of an abacus: one of these divisions on the base would become the diameter of the column, and nine their height, the other eight on the base would be devoted to the intercolumniations, and the upper three of the height to the entablature. The columns, 9 diameters in height, would thus comprise 36 squares, the intercolumniations 72, and the entablature and half pediment 36; consequently the columns and entablature would be equal in quantity, and the intercolumniations half the whole, or equal to the contents of the supports and supported.

Roman Hexastyle. Corinthian, Maison Carrée at Nismes. — This beautiful temple has undergone several restorations; its entire width and height to the apex of the pediment is 43 feet 8 inches, from whence it has derived its name. The height of the columns, includ-

ing base and capital, is 29 feet 6 inches, that of the entablature 6 feet 9 inches, and of the pediment 7 feet 5 inches; taking away half the height of the pediment, we have 39 feet 11 inches and 6 parts, which may be considered as 40 feet; this multiplied by the width produces for the entire area 1746 feet 8 inches. The superficial content of pediment and entablature, 456 feet 8 inches, is obtained by multiplying the entire width by 10 feet 5½ inches, the height of the entablature and half the pediment, which superficies is only 20 feet 2 inches more than a quarter of the whole. The united diameter of the six columns is 17 feet 6 inches, and that of the intercolumniations 26 feet 2 inches, so that they are in the proportions to each other of 2 and 3, the whole being 5, one having an area of 515 feet 9 inches, the other 772 feet; when added together they are nearly three times the area of the part supported.

The proportion between the columns and intercolumniations of the temple at Assissi is also similar, the height of the columns is 32 feet 10 inches, and the total width of the six 52 feet, which dimensions multiplied together produce 1707 feet 4 inches, one-fifth being 341 feet 6 inches nearly.

The area of the columns is 684 feet, and that of the intercolumniations 1023 feet 4 inches, giving a proportion of two-fifths and three-fifths. The entablature, pediment, and pedestals upon which the columns are placed seem to have undergone a change since their erection. If the whole extent of an hexastyle portico be divided into 18 parts, and one be called the diameter, to obtain the same proportions as those laid down for a tetrastyle portico, the height up to the centre of the pediment must include 12 only of those parts, which would give a portico of a square and a half, comprising 216 squares; the 6 columns, each 9 diameters in height, would require 54; the 5 intercolumniations, double that number, or 108, and the entablature and half pediment 54.

Roman Octastyle. — The Pantheon at Rome, which has a portico of 8 columns, is one of the best examples that can be selected for examination. The total width is 109 feet 10 inches; the diameters of the eight columns 39 feet 5 inches, and the seven intercolumniations 70 feet 5 inches, or nearly in the proportion of 1 to 2. The height of the columns is 46 feet 5 inches, and that of the entablature and half pediment 23 feet 2½ inches, together 69 feet 7½ inches, nearly a square and a half, the area of which is 7647 feet 2 inches.

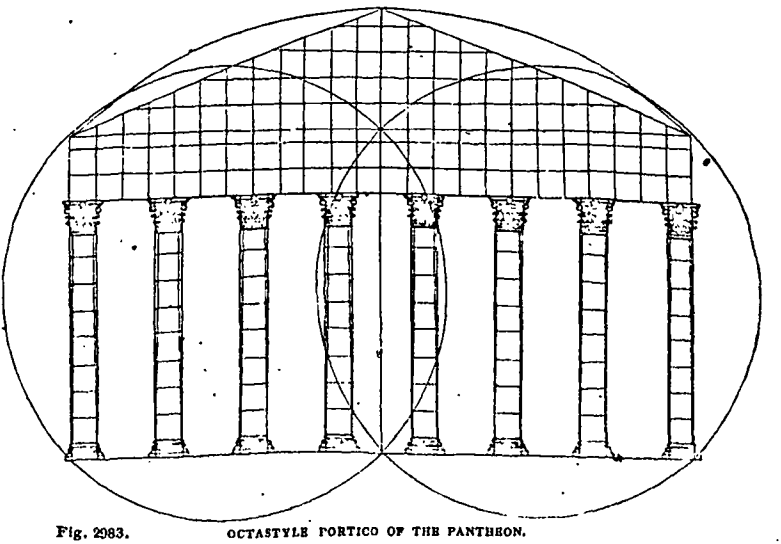


Fig. 2983. OCTASTYLE PORTICO OF THE PANTHEON.

The united diameter of the columns, 39 feet 5 inches, multiplied by their height, gives 1829 feet 7 inches, and the collected intercolumniations multiplied by the same height will be 3268 feet 6 inches: multiplying 109 feet 10 inches by 23 feet 2½ inches, we obtain for the area of the entablature and pediment 2549 feet, which, rejecting parts of an inch, will, when added to the two other calculations, make up a sum agreeing with the entire area.

		Feet.
The supported is		2549
The area of columns	1829·7	
of intercolumniations	3268·6	5098
Together		7647

A line drawn through the centre of the pediment, another at half the height of the columns, and a third under the entablature, would divide the height into three equal portions, proving that, in this example, the Romans made the part supported one-third of the whole, and divided the other two between the columns and their intercolumniations. The shaft of each column is cut out of a single block of granite; they are not sufficiently delicate to be exactly in the proportion of half the quantity contained in the intercolumniations; but if allowance be made for their diminution, the difference is not very great. The whole width being 109 feet 10 inches, the third, 36 feet 7 inches and 4 parts, is nearly a mean between the collected diameters of the top and bottom of the shaft, making the intercolumniations double the quantity contained in the supports, or equal to that of the supports added to the mass they carry. The whole would then be divided into four, as in the previous examples of the Ionic, and two portions given to the intercolumniations.

The Pantheon Portico is a double square without the pediment, or nearly so, the length of the level cornice, which crowns the entablature, being double the height of the order: this, no doubt, was the outline of the proportions before the heavy pediment was placed upon it, which in all probability was heightened beyond the ordinary rise of a ninth, for the purpose of concealing the wall behind it. The Roman proportions are frequently made independently of the pediment; the tetrastyle porticoes are a square, the hexastyle a square and a half, and the octastyle, as in this instance, a double square without it.

To set out an octastyle portico, in which half the pediment should be comprised within the double square, after dividing the width into 24 and the height into 12, which multiplied produce 288 squares, 72 are given to the column, the same to the entablature and half pediment, and double that, or 144, to the intercolumnations, or proportions similar to those laid down for the tetrastyle and hexastyle porticoes. The columns in such a case would be nine diameters in height, the entablature and half pediment three: supposing the latter to rise a ninth of the span, the remainder would be distributed among architrave, frieze, and cornice.

We have endeavoured to show the proportions required in a tetrastyle, hexastyle, and octastyle portico among the Dorians, the Ionians, and their followers the Romans: the square and a half, or the double square, were the outlines or boundary figures from whence the other proportions were deduced.

The great difference of character in the Doric and Ionic designs arises from the distance at which the columns are placed, which affects the proportions of the entablature laid upon them, as well as that of the columns themselves; where these are six diameters in height or consist of six cubes, they are made to carry the same quantity, whatever may be their distance apart, and where drawn out to nine diameters, they have only their own weight to support; but the form given to this weight, or the proportions of architrave, frieze, and cornice, vary, as the intercolumniations are of one or more diameters.

It has been too generally considered that the orders derived their proportions from the lower diameter of the columns, without reference to their application: this has produced a variety of design, but at the same time occasioned a great departure from the true principles, and led to very important errors. The Tuscan, the Doric, the Ionic, the Corinthian, and Composite orders have been laid down in modules or measures of various kinds, which the young architect has adopted as mere isolations, regardless of the many other considerations which have stamped beauty on his model; hence we have imitations, but soul is wanting.

The Doric order is treated of as so many diameters in height according to its age, and the entablature is said to be heavy or light, as it was of early or late execution; the other orders have been chronicled in a similar manner, and architecture has been fettered, and its great principles lost, or at least neglected: it is true that the outline which bounds the figure has undergone but few changes, but the subordinate parts or the filling-in are susceptible of interminable variety. An object inscribed within a circle is perhaps the most easily compassed by the eye, next that within the square, and when a building is vast, and distance is necessary to comprise a view of the whole, the double square; beyond this the ancients seem seldom to have gone for the proportions of their façades, or of a portico intended to be seen in front. After the masses were proportioned, their decorations were more various than the buildings themselves; no two are perfectly alike, but the great difference is in their ornaments and enrichments, or in the number of diameters contained in the height of the columns.

The Parthenon and Pantheon porticoes are both octastyle, each admitted to be as beautiful as they can be—one the perfection of sober grandeur, the other of cheerful lightness; one Greek Doric, the other Corinthian, both comprised within a double square, and having their columns equal in quantity to the mass of entablature they support: where, then, is the difference between the two examples? It results, as we have already seen, from the material in the one occupying two-thirds, and in the other only half the entire area. In the façade of the Parthenon the eye has one-third void only to contrast with the solid matter, and in the Pantheon half, which proportions seem to have been established by the Ionians, and usually adopted by the Romans.

In proportioning the architrave, frieze, and cornice, care must be taken that no more is laid upon the columns than their own bulk: when the latter are one diameter apart, this quantity will be greater in height than when they are further distant; so that the greater the intercolumniation, the lighter in appearance will be the entablature, the columns still bearing the same weight, nor need they be increased after it is ascertained that they are competent to their duty: to do so would be to employ material in excess, which it should be the aim of an architect to avoid.

If we now examine the portico of the Pantheon, we cannot fail to perceive the agreement existing between the parts supported and their supports.

	ft.	in.
The mean diameter of the columns is	4	7
Their height, including capital and base	46	5
The solid content of each	765	10·6
Consequently the cube of the whole 8 is	6027	0

	ft.	in.
The mean width of the architrave and frieze is	4	3
Their height	6	8·3
The solid contents of the entire length, 110 feet, is	3125	11
The mean width of the cornice is 7 feet, length 114 feet, height 3·6 feet, and its cubical contents	2793	0
The solid content of entablature	5918	11

which leaves little more than 100 cubical feet of difference between one and the other; and if the crown moulding returned on the flank be comprised, the quantity contained in the entablature would equal that of the eight columns.

The pediment is omitted altogether in this calculation, it being in reality, though not in appearance, an additional load for the eight columns beyond their regular entablature, which is of marble, and weighs probably 452 tons; the granite columns with their marble bases and capitals are something more than that quantity, and these, including the entablature and pediment, probably contain upwards of 1000 tons of material.

The Capitals of the Columns of the Pantheon are admitted to rank among the best examples found in Rome: though not so highly and elaborately worked as those which decorate the columns of the temple of Jupiter Stator, yet they are remarkable for the elegant

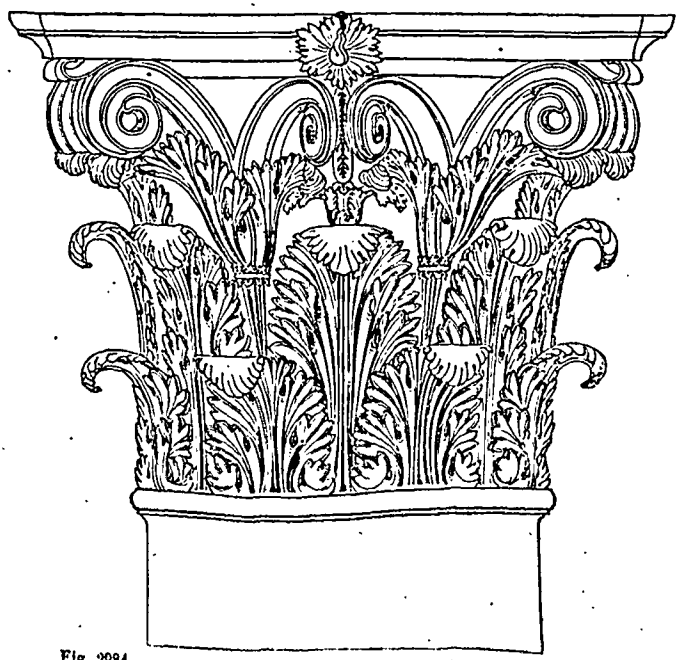


Fig. 2984. CAPITALS OF THE PANTHEON.

arrangement of the ornaments: further details will be found in the Architectural Antiquities of Rome, whence this has been selected.

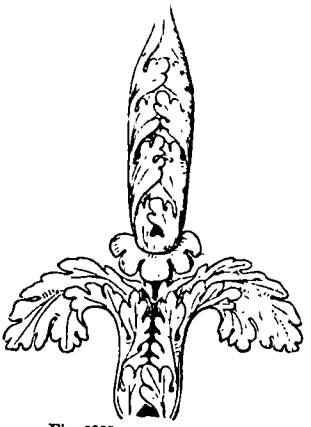


Fig. 2985.

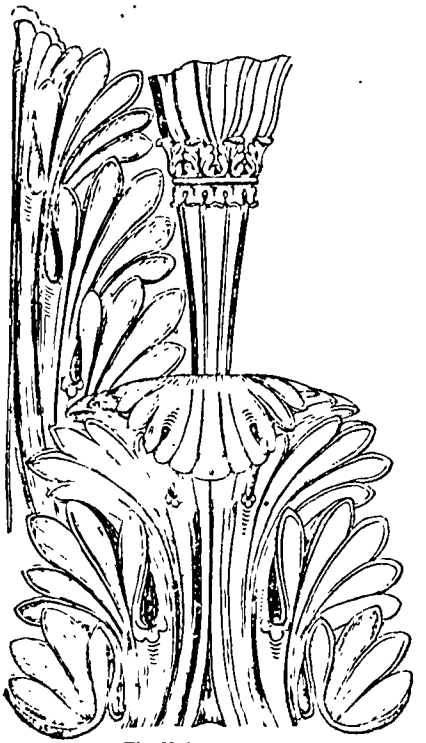


Fig. 2988.

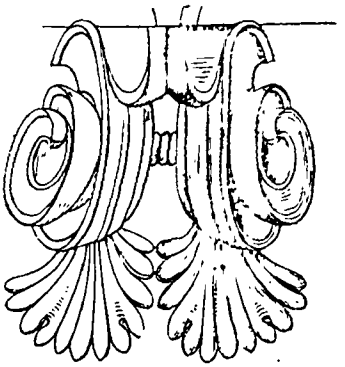


Fig. 2986.

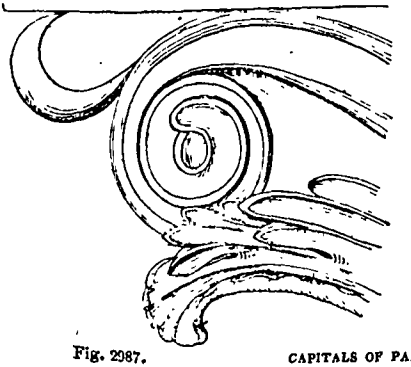


Fig. 2987.

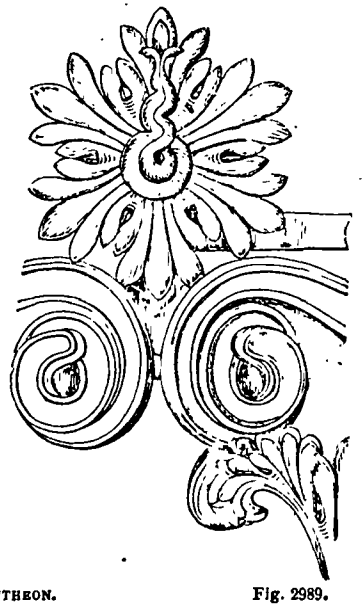


Fig. 2989.

CAPITALS OF PANTHEON.

Although the Romans did not improve the arts which the Greeks had spread among them, by the introduction of the arch they materially altered the character of the architecture practised before the time of the Republic: this feature alone produced entirely

different construction, and the several changes it has since undergone in form have served to establish a variety of styles, as we shall afterwards find.

Sewers, aqueducts, bridges, theatres, amphitheatres, baths and triumphal arches, all exhibit the arch in its most useful application, and as did the halls of the baths vaulting of stupendous span; the dome of the Pantheon being 142 feet 6 inches in diameter internally, covered by a hemispherical dome.

Symmetry, as understood by Vitruvius, seems to relate more to the proportions of the façade than to those of the detail; but he doubtless intended it to be understood that

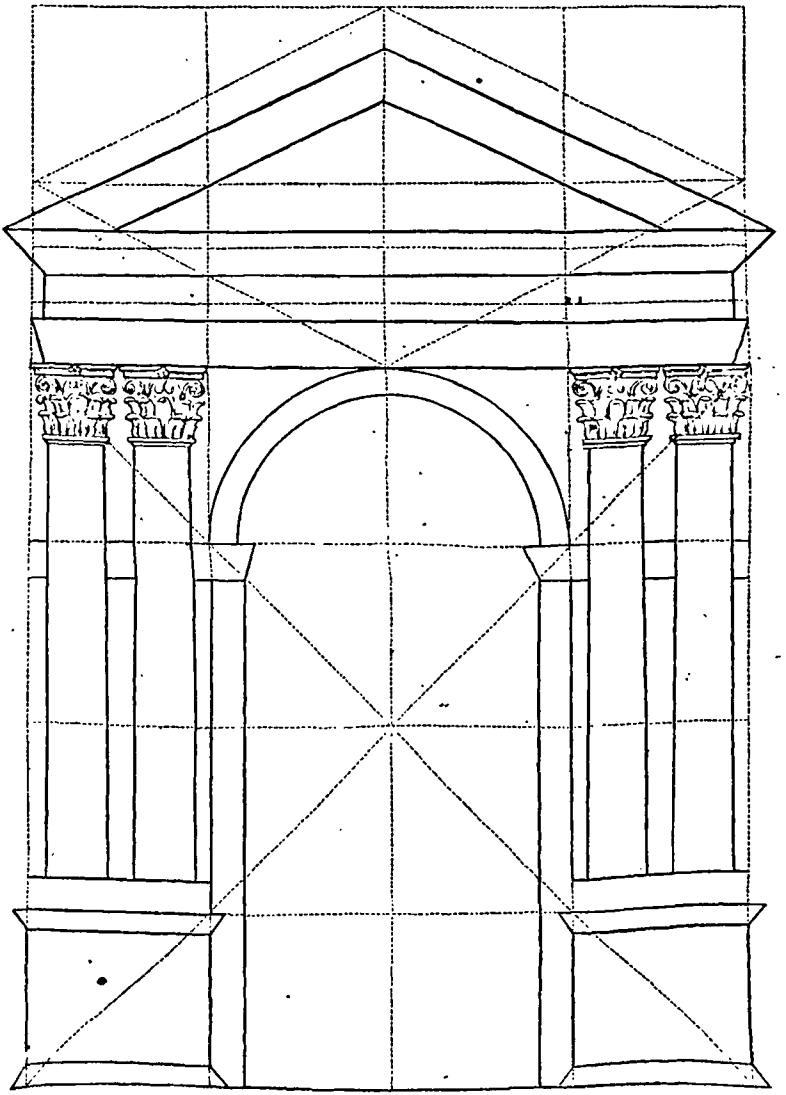


Fig. 2990. ARCH OF POLIPHELE.

perfect harmony should subsist between them as well as between each particular member, however subordinate; as in the well-formed human figure, all the limbs being in due proportion, the whole when combined produces true symmetry: and the same author insists very strenuously on a careful study of the rules upon which this is founded, proving that the effect desired cannot be produced by a mere effort of fancy, or what is commonly called taste.

A building, though entirely devoid of ornament, may be rendered beautiful by the justness of its proportion, and the richest edifice wanting in this never can excite admiration: façades having but height and breadth, these two dimensions must be equal to each other, if we adopt the symmetrical proportions prescribed by Vitruvius, for he observes "the square includes the human figure either lying down or standing in an erect posture, the arms being stretched out." Temples, triumphal arches, and other buildings left us by the Greeks and Romans were decidedly designed upon this principle, as were most of the façades of the religious structures erected since the fall of the Roman empire.

In the "Songe de Poliphele," originally published in Italian by Aldus in the year 1499, are some observations on setting out a façade, which convey some idea of the principles adopted for the formation of a perfect and harmonious design on the revival of Roman architecture.

"Draw a square figure, divided by three perpendicular and three horizontal lines, at equal distances from each other, forming sixteen squares; on the top of the square add a half square, which, similarly divided, makes altogether twenty-four squares: in the lower square draw two diagonals, crossing eight squares in the same manner; then form a lozenge above the great square, tracing within it four lines on the four principal points that separate the four sides of the void."

After understanding this figure, I thought within myself what can modern architects do, who esteem themselves so learned without letters or principles? They neither know rules nor dimensions, and therefore corrupt and deform all sorts of buildings, both public and private, despising nature, who teaches them to do well if they would imitate her: good workmen, besides their science, may enrich their work either by adding to or diminishing therefrom, the better to please the eye, but the mass should remain entire, with which all should be made to harmonise. By the mass is understood the body of the edifice, which, without any ornament, shows the knowledge and spirit of the master, for it is easy to embellish after any invention; the distribution and arrangement of the parts is also a matter of consideration; hence we may conclude that any workmen or their apprentices know how to ornament a work, but to invent lies only in the heads of the wise.

Taking from the square and a half, the lozenge and the diagonal lines leaves the three perpendicular and the three horizontal, except that in the middle, which terminates in the centre of the perpendicular, cutting it into four parts or portions; by this rule will be found two perfect squares, one above and one below, each containing four small squares, which form the opening or doorway; now if you take the diagonal of the lower square, it will show you what thickness must be given to the centre of the portico; if you carry it straight, the line will serve to denote the architrave: and the point of the centre of the upper square will show you the centre of the arch or curve to be given to the door; turning a semicircle it will rest on the transverse line, which cuts the square and a half into two equal parts; but if done by any other means I do not esteem it perfect. This method was invented by ancient and expert masons, and observed in their arches and vaults, to give them both grace and solidity; the pedestal on which the columns rest commences at the level of the pavement by a plinth, and the whole is a foot high, furnished with mouldings; one portion is divided into architrave, frieze, and cornice, the latter being something more than the others; that is to say, if the architrave and frieze contained five parts, the cornice should be six. The whole twenty-four squares form a square and a half; then divide the upper half into six parts by five horizontal and five perpendicular lines, and draw a line from the centre of the fifth transverse to the corner of the great perfect square, where the architrave commences; then draw it perpendicular on the key of the archivolt, and it will show you the height to be given to the frontispiece above, the extremities of which should unite and relate to the projection of the cymatium and its mouldings.

General Principles.—It would appear that all the principal Roman triumphal arches with single openings were a square, either comprising or excluding their attics: that the centre from whence the archivolt was struck was the centre of the square, or if the façade was more than a square, as the arch of Trajan at Ancona, then where the two diagonals crossed the centre was fixed. The width of the opening is generally half the entire extent, sometimes three parts out of seven.

These triumphal arches were generally surmounted by a group of figures, or the car and horses of the conqueror, accompanied by his companions in arms and the trophies obtained from the enemy; these, as shown on several medals, appear to be equal in height to $\frac{1}{3}$ of the entire edifice upon which they are placed, the attic and entablature representing $\frac{1}{3}$, and the columns and pedestals the other $\frac{1}{3}$; and as the former are nearly equal in their height, it follows that the horse and his rider, or the car and its triumphant hero, were double the height of the pedestal on which they were placed, for so we may consider the attic which contained the inscription, the body of the arch being a perfect square, and in correct proportion, without the attic. The depths of these arches varied; that of Constantine at Rome is nearly the same as the width of the great centre opening; many of the others are less than that proportion; but it seems that the cube was the measure that

bounded the proportions, as shown in fig. 2995. The several Roman examples selected differ in arrangement, but not in principle, from the description given by Poliphele: take away the pedestals on which the columns are placed, and then four squares in height include half the tympanum, and eighteen squares the entire figure, 6 of which may be considered as devoted to the arch, and the other 12 to supports: or, if we comprise the whole façade in 20 squares, and abstract the 8 which belong to the opening between the pedestals, we have 4 for each pier or support, and 4 for the entablature, the supported being only ½ the quantity contained in the two supports: resistance to the arch, or its thrust, requires a different arrangement from that of a portico, but we nevertheless find definite proportions made use of, and a double quantity given to masses which have to bear weight as well as resist thrust.

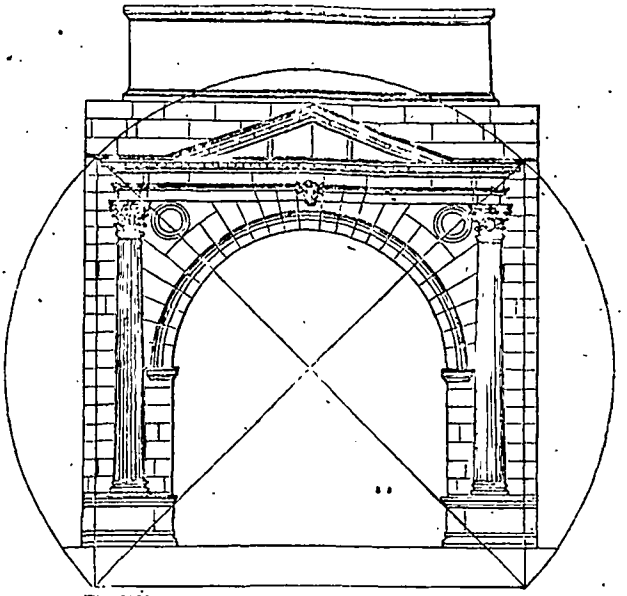


Fig. 2991. ARCH OF AUGUSTUS AT RIMINI.

The Arch of Augustus at Rimini has the height of its order determined by the length of the frieze.

The Arch of Augustus at Aosta resembles that of Titus in arrangement; it is a perfect square comprising the attic.

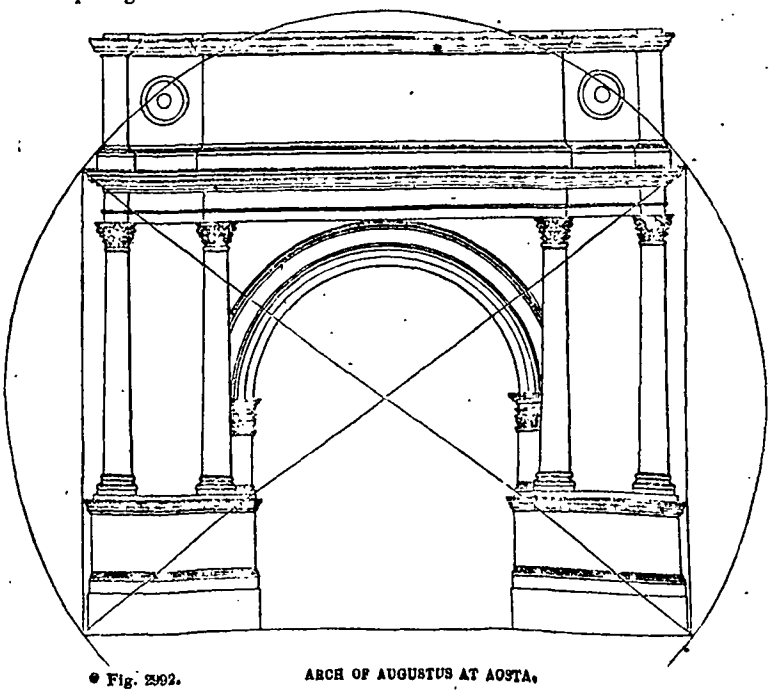


Fig. 2992. ARCH OF AUGUSTUS AT AOSTA.

The Arch of Sergius at Pola is a perfect square, without attic, like that of Titus.

The Arch of Titus at Rome, raised by the senate and Roman people to commemorate the conquest of Judæa, is one of the best examples of proportion that remain: built of white marble, it is a monument of constructive art, some of the blocks being 9 feet square, and 2 feet thick; the arch is composed of eleven voussoirs 16 feet deep. For a detailed account of its construction and ornament the reader is referred to the "Architectural Antiquities of Rome"

The proportions are a square, as is the opening of the archway, up to the springing; and not a double square, as described by Serlio. The pedestals are in height nearly half the opening of the archway, which Palladio observes was the ordinary proportion given by the ancients. The entire length of the upper member of the cornice in this example is 48 feet, which dimension corresponds with the entire height, almost to a fraction: the width of the opening is 17 feet 6 inches, a trifle more than one-third of the entire width: bounding the façade by a parallelogram, excluding the attic, and drawing two diagonals, we obtain the centre from which the arch is struck, which rule will apply to the other

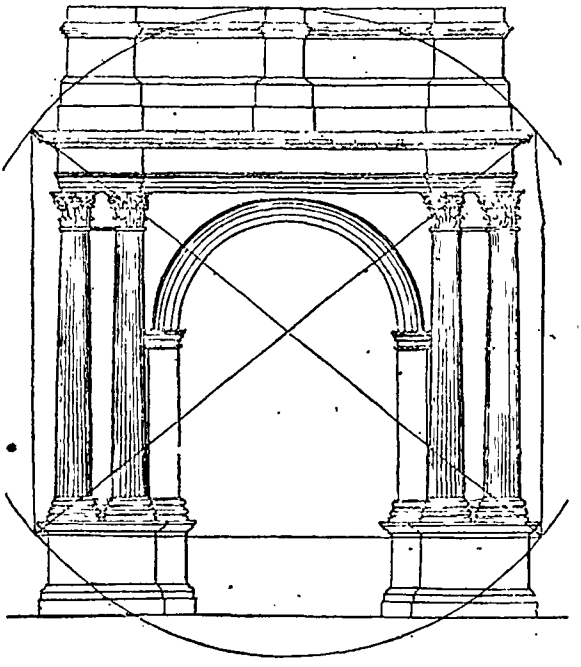


Fig. 2993. ARCH OF SERGIUS AT POLA.

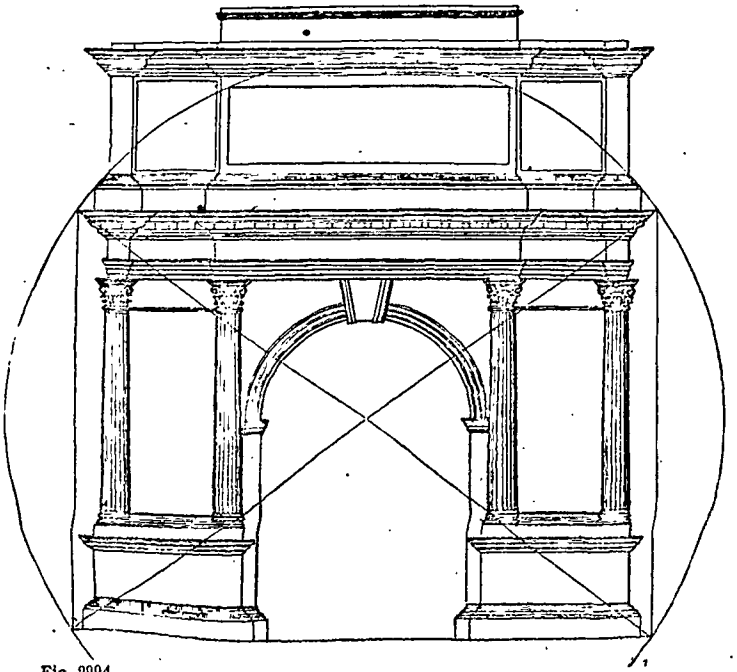


Fig. 2994. ARCH OF TITUS AT ROME.

triumphal arches with a single opening, though varying materially from the principles laid down by Poliphele, and adopted by Serlio and other architects at the revival of Italian architecture. The Arch of Titus is a square comprising its entire façade; that of Poliphele a square up to the under side of the entablature; consequently, the opening of the triumphal way is in width half the height to the top of the impost upon which the archivolt rests, while in the more ancient the entire aperture without the arch is a square.

In the Arch of Poliphele the entablature and pediments are nearly equal in quantity to each of the piers upon which they are carried; and the piers themselves are in width only one quarter of the whole-breadth of the façade: it will be found, however, that nearly the same proportions exist between supports and supported in both examples.

The Arch of Augustus at Susa has a single arch: proportion a square to the top of the entablature, opening a square to the springing: width divided into four, two given to the opening and one to each pier, which has a three-quarter column at the angle: attic as high as piers are wide.

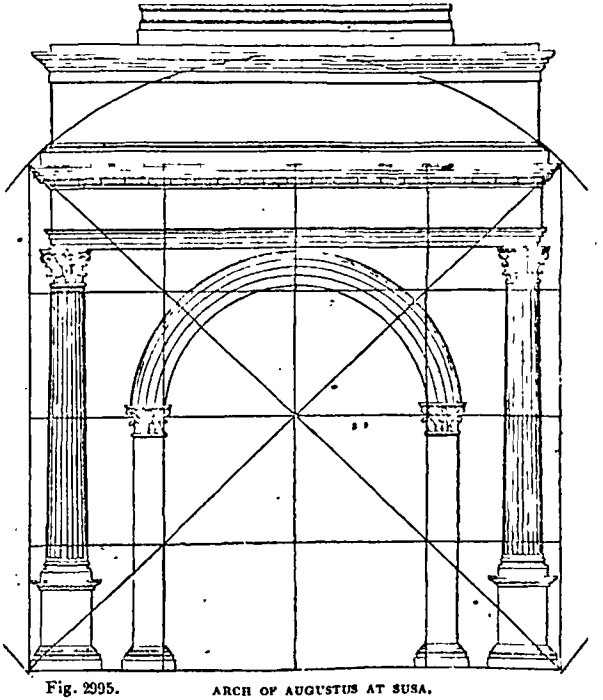


Fig. 2995. ARCH OF AUGUSTUS AT SUSA.

In arches with three openings, as those of Septimus Severus and Constantine, these

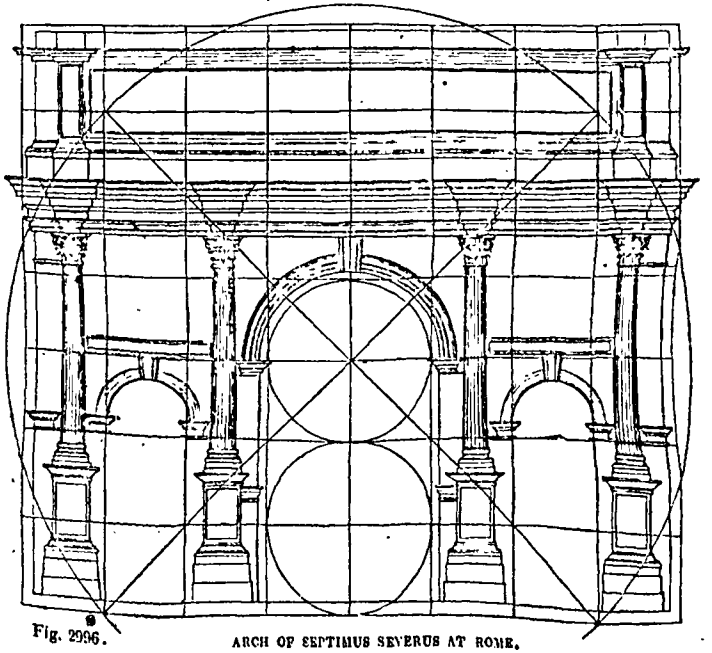


Fig. 2996. ARCH OF SEPTIMUS SEVERUS AT ROME.

occupy one-half the width, and the piers the other: where the diagonals of the figure cross is the centre, from which the principal arch is struck.

The Arch of Trajan at Beneventum.— Circle struck from the centre which describes the archivolt; comprises all within it except the attic: division of width into seven, two for each pier, three for centre; attic half the height of the order.

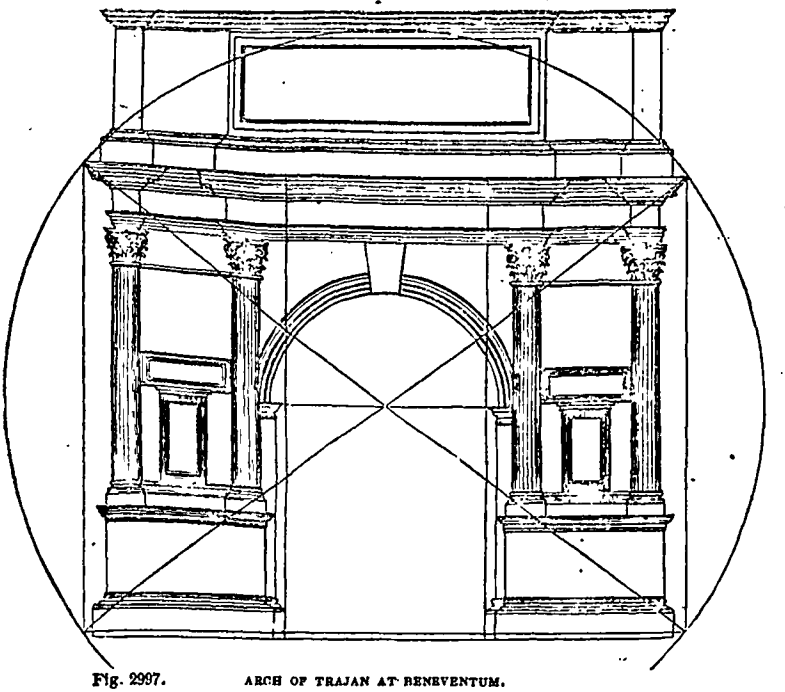


Fig. 2997. ARCH OF TRAJAN AT BENEVENTUM.

In the foregoing examples, we have attempted to show that the beauty which belongs to form in architecture rests upon one principle based on the laws of nature, and that the first element in a good design is the proportion of the parts as well as the whole: nothing has more misled the critics upon this subject, as well as architects themselves, than implicitly following the rules laid down for drawing the orders. In treating upon the antique, they have frequently been right as far as regards the letter, but essentially wrong in the spirit. The laws of nature do not vary, nor do our organs of sense or perception, and what was apparently fit and proper in the opinions of the Greeks is equally so at the present day: in their sculptures we never find a man represented carrying more than his own weight, and such laws ought to be our guide.

After the destruction of the Roman empire, the character impressed upon architecture by the Greeks was lost: other styles arose in succession, which have been designated as Byzantine, Romanesque, Lombardic, Saxon, Norman, Saracenic, and Pointed. The five first retained the semicircular arch, and only differed in the quantity of material employed: for examples of the three first-mentioned we must refer to a work entitled "Architecture of the Middle Ages at Pisa," by Edward Cresy and G. L. Taylor, containing measurements made in 1817, in which is an engraving of the monument of the architect who executed all the work in the pointed style introduced in the celebrated baptistery, supposed to have been the work of the twelfth century; the discovery of this monument satisfactorily proved the date when that building was altered from the original Romanesque character.

In England the Saxon style prevailed to the time of the Conquest (1066), and the Norman, which succeeded, varied but little from it. The pointed arch is found as early as 1180; after which the Lancet style became general, and continued to be used till about 1272; to this succeeded the decorated or geometric, which was practised till 1326, when the perpendicular style was universally adopted, and continued till the early part of the sixteenth century, when classic architecture was again revived. Our attention must not, however, be directed to the decorative portions of either style, but to the construction, from the study of which some valuable lessons may be deduced.

The Saxon manner of Building. — A division of the transept of the cathedral at Winchester has been selected as the best authenticated example of the style in use previous to the Norman Conquest. In a paper read before the British Archæological Association at their second annual congress, held at Winchester in August, 1845, the author gave his reasons for supposing it to be the work of St. Athelwold, for which the reader is referred to its "Transactions," recently published.

Arches upon arches enabled the Saxons to continue their walls to a considerable height, the openings between the piers being proportioned as those of the Roman buildings in the time of the emperors. The plans of the piers differ from those previous to the introduction of Christianity: in Britain both the Greek cross and the circle are applied to them.

At Winchester Cathedral the columns of the triforium recede within the pier, and are set round a circle, (fig. 2999.); the passage in the walls of the clerestory is shown at the side; in another portion of the same building is a similar arrangement in less massive piers. (fig. 3000.)

The Saxon churches were generally divided into three tiers or stories, viz. a lower arcade, a triforium, and clere-story above; and such was the solidity and thickness of the walls, that buttresses were altogether omitted, the outer face of their buildings in this particular bearing a closer resemblance to the Roman than the Norman, although the workmanship was rude, and the decoration scanty.

The proportions found in Saxon buildings are the same as in the Roman, which, without doubt, they took for their models. The circular temple of the Pantheon at Rome, 142 feet 6 inches diameter internally, and 183 feet 8 inches externally, contains the proportions of two-fifths wall and three-fifths void; the area of the latter being 15,948 superficial feet, and of the former 26,493 superficial feet; the difference of these areas giving 10,545 feet for the area of the walls.

We have already seen that in the Coliseum at Rome the points of support are about one-sixth of the entire area of the plan; and the proportions of both these buildings have been admired for nearly 2000 years, the one vaulted, the other uncovered.

Generally the walls and piers of our Saxon cathedrals occupy from one-third to two-fifths of the entire area; in their sections one-third is devoted to walls and piers, and the remainder divided between the nave and side aisles.

The division of the cathedral at Winchester exhibits very perfectly the Saxon manner of building; the piers that support the lower arches are 10 feet wide, and the clear openings between them 12 feet 1 inch. The nave and transepts retain their original construction; in the former under the casing executed by William of Wykeham, and in the latter it is seen in its full purity. The choir stands over the crypts built by St. Athelwold, and though

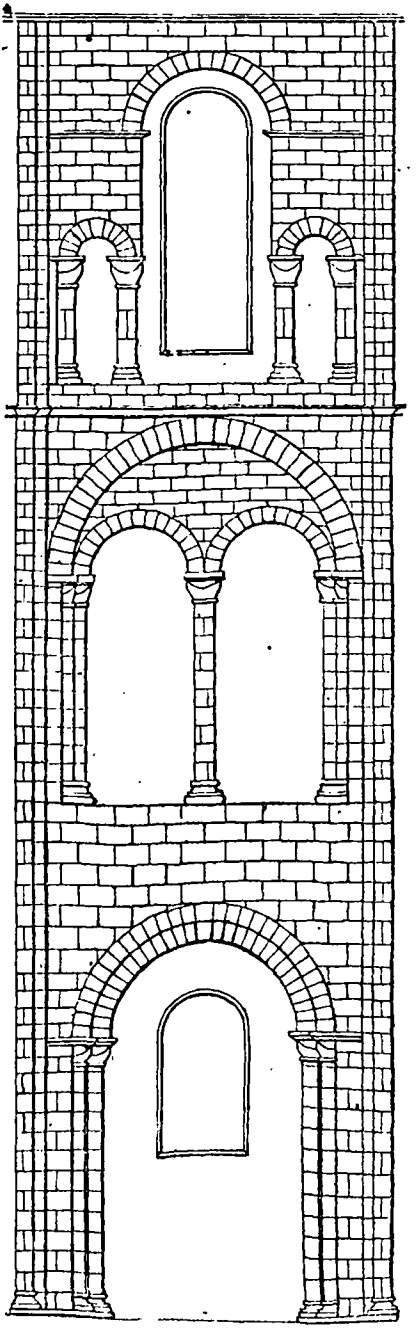


Fig. 2998. WINCHESTER CATHEDRAL.

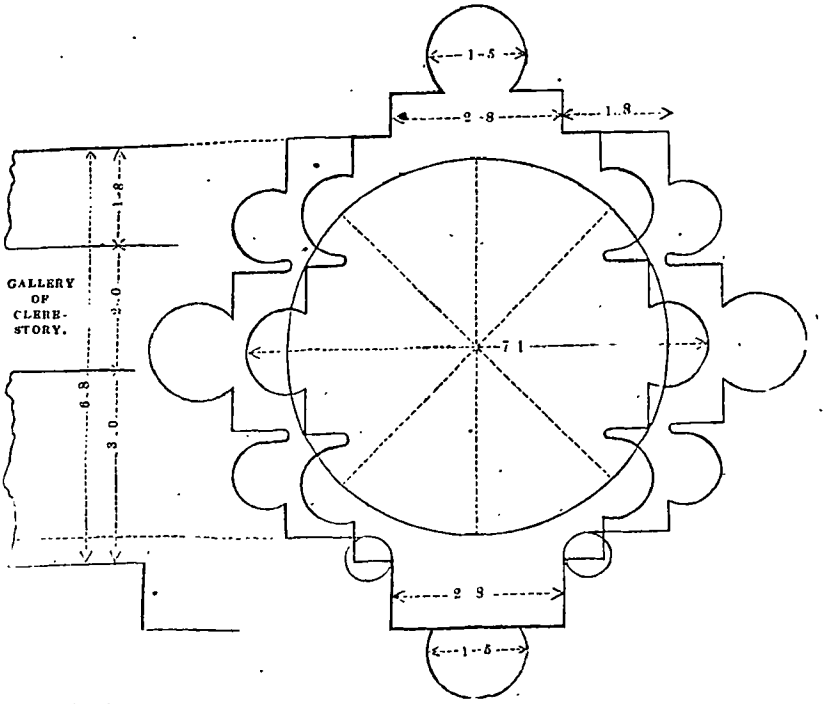


Fig. 2999. PIER IN NAVE AT WINCHESTER CATHEDRAL.

somewhat changed by the Normans, it yet retains the dimensions given to it by its celebrated Saxon constructor.

The small piers, one of which, in the south transept, is nearly perfect, are set out with great regularity, and measure 9 feet 8 inches from west to east, and 8 feet 2 inches from north to south; their form is that of the Greek cross, composed of five cubes, each 2 feet 7 inches in width, with large and small columns placed around them to receive the mouldings that decorate the arches: six of these columns have their centres on the same circle: it is evident that the hexagon, or the duplication of the equilateral triangle, was applied, and that the whole was set out by one conversant in geometry, and acquainted with the proportions of the cube. The Greek cross, which defines the solid mass, is continued through the triforium and clerestory up to the timber roof. The columns of the triforium, set round the inner circle, are partly cut into the lateral arms of the Greek cross, but the face of the shafts of the columns are in a line

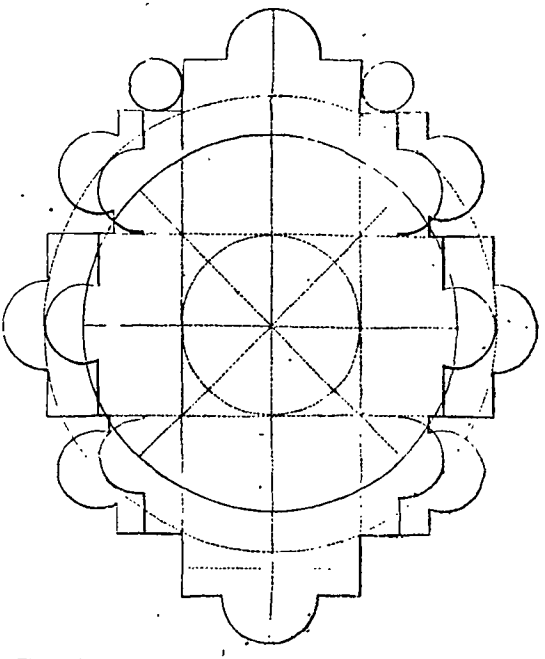


Fig. 3000. PIER AT TRANSEPT AT WINCHESTER CATHEDRAL.

with its outer side. The centre of the pier is preserved throughout, and so placed as always to balance the masses around it equally. The circular shafts at Gloucester Cathedral, Tewkesbury Abbey Church, and several others, were probably of earlier date than pillars formed of several shafts; those in the church of Saint Germain des Prez, at Paris, are delicate examples of the former style.

That aisles, galleries, and passages, belonged to the construction of a Saxon church, we have sufficient evidence in the accounts left us by contemporary historians; but the present subject is almost conclusive on this point, there being a preparation for a wall 6 feet 8 inches in thickness, containing the passage 2 feet in width, indicated by the plan of the pier at fig. 2999. The arrangement of the columns shows that there was no intention of vaulting the side aisles, for the two which carry the cross springers appear to have been added some time after the original construction, as were also those in the pier, fig. 3000.

Athelwold is supposed to have executed the whole of this work before the year 980: the mouldings throughout are rudely cut, the capitals of the main pillars being the only portions which are at all enriched by sculpture, and they are very simply carved.

The Norman manner of Building can scarcely be said to differ from the Saxon, though the masons employed after the Conquest certainly acquired a superior knowledge in their art. The ornaments which we find in Norman buildings had all been previously used by the Saxons; hence the difficulty of distinguishing the works of one from the other: where written authority is not handed down to us, we can only judge by the difference of the workmanship; it cannot be denied that there were many very able masons among the Saxons, who were qualified to raise buildings and enrich them with sculptured ornament.

The finest examples of Norman work may be seen at Caen and its neighbourhood, and have been engraved from measurements taken by the late Mr. Pugin.

In England the same style prevailed throughout our religious structures; there is a great similarity of arrangement, and little variety of ornament. The Norman style was generally adopted after the Conquest, but that named by the monkish historians the "Opus Romanum" was continued in many of our parish churches, as well as in some larger buildings. The Norman pillar was sometimes composed of a cylinder with four small half columns attached, as at Amiens, which is 7 feet 2 inches diameter.

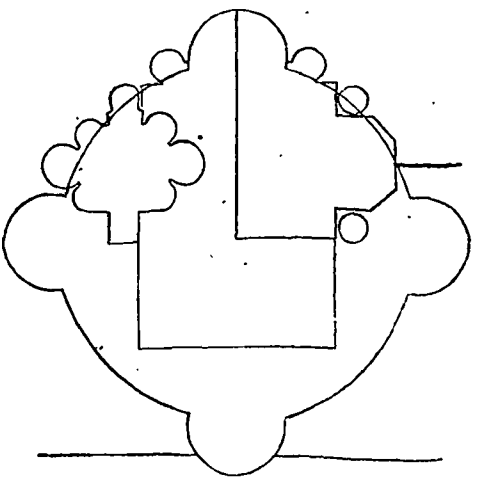


Fig. 3001. PIER AT AMIENS.

For the Saracenic or Arabian Styles we must refer to the beautiful work recently published by Mr. Owen Jones, where the decorative parts of this curious and highly ornamented architecture are admirably given, and proceed to the description of the principles which guided the constructors of pointed architecture.

The Lancet Style succeeded the Norman, and we find it well defined in many churches and cathedrals as early as the year 1180; in it decoration was sparingly introduced, and throughout every part of the design there was simple uniformity, and a display of a considerable knowledge of geometry: the heads of the windows and doors were formed of a pointed arch, constructed upon an equilateral triangle; all the mouldings which surrounded those apertures were delicately formed, and had both capitals and bases; this style was practised till 1230, when it was followed by another, which by some writers has been termed

The Early English or the Geometric Style, from the manner in which the several portions of a building were set out; and we find it adopted generally up to the year 1280.

Salisbury Cathedral, founded by Bishop Richard Poore, in the year 1220, was finished in 1260. Its plan is that of a Greek or patriarchal cross, the extreme length being 480 feet, that of the great transept from north to south 232 feet, and that of the lesser transept 172 feet: the stone used for the external walls and buttresses was brought from the quarries at Chelmark, which lies about 12 miles distance, westward from the city. The middle

of the walls is filled in with rubble, and the shafts of the columns are of marble, from the Purbeck quarries. At the intersection of the nave with the great transept rises a noble stone tower and octagonal spire, the total height of which is 400 feet; the stone of the spire is in thickness about 2 feet to the height of 20 feet above the tower, after which it is only 9 inches in thickness to the summit: this spire, though braced and strengthened throughout by timbers and ironwork, has declined from the perpendicular 22½ inches; but since 1681, when the observation was made, there has been no further declination.

The walls, after they were carried up to the floor of the triforium, appear to have been increased by corbelling, as if it had been doubted whether, as originally set out, there would be sufficient strength to carry the cross springers of the vaulted nave; the total width is exactly 100 feet. The clear width of the nave, as measured on a level with the triforium, is 33 feet 3 inches, and that of each side aisle half that dimension, or 16 feet 9 inches; had this last been 16 feet 7½ inches only, the proportions shown by a section would have been exactly one-third for walls and two-thirds for voids; after appropriating the third of the 100 feet to the walls, half the remainder is given to one side, and half to the other; we also find that each of these dimensions of 16 feet 8 inches is divided into three, two parts of which are given to the outer wall and buttress, and the other to the main pillar that divides the nave and side aisles, or nearly so.

The inclination of the arched buttresses is not such as to resist the spreading of the vault at its base, the knowledge of their use not having then been attained. The height of the vaulting of the nave from the pavement is 81 feet.

Wells Cathedral has some peculiarities in its construction, particularly in the application of its arched buttresses: they pitch against a stone corbel inserted below the springing of the

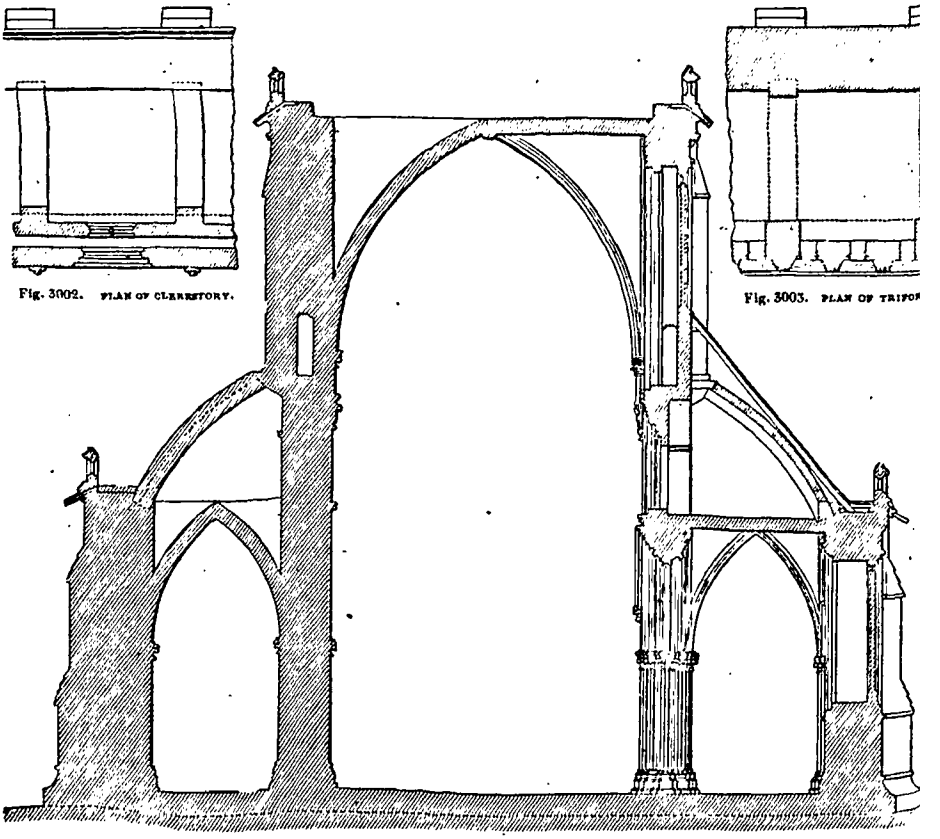


Fig. 3002. PLAN OF CLERESTORY.

Fig. 3003. PLAN OF TRIFOR

Fig. 3004. SECTION OF WELLS CATHEDRAL.

middle vault, and a tangent drawn at the back of the vault and elongated determines the inclination of the top of the flying buttress: here some improvement is shown upon those

at Salisbury. The masonry of the arches is admirably constructed, and the joints all radiate to a common centre.

The total width of this cathedral from face to face of the buttress is 86 feet 5 inches, and that of the nave 31 feet 10 inches, instead of 28 feet 9½ inches, as it would have been if a third had been adopted; the side aisles are also diminished in consequence, being only 18 feet 7½ inches in the clear; they are, however, equal to the buttress, outer wall, and main pillar added together, the first projecting 2 feet 8 inches, the second or outer wall being 6 feet in thickness, and the piers 5 feet diameter; whilst the width of the side aisle measures 18 feet 7½ inches, an approximation sufficiently near to suppose that the proportions of thirds was still adopted in practice. The nave has been increased at the expense of the side aisles, and its height is 68 feet 9 inches to the top of the vaulting from the pavement.

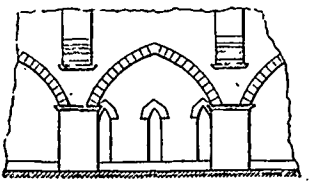


Fig. 3005. TRIFORIUM, INSIDE.

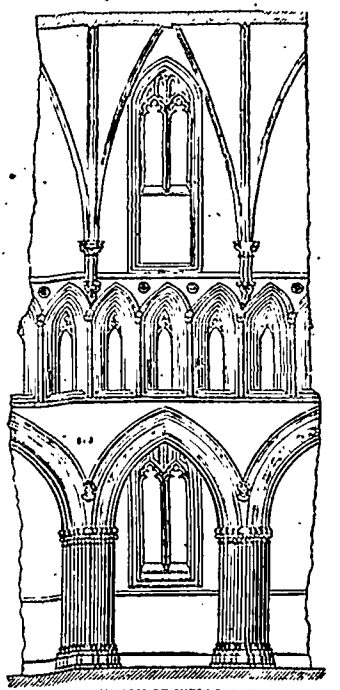


Fig. 3006. DIVISION OF WELLS CATHEDRAL.

Chapter House at Wells, erected between the years 1293 and 1302, is an octangular building of great beauty. A section through the buttresses shows that two equilateral triangles crossing each other have determined the mass and void, which are in the proportion of one to two, or the thickness of the two walls is equal to one-third the entire diameter: the base line of the triangle, on which the supports of the crypt are placed, clearly indicates this arrangement. Of the twelve equilateral triangles comprised in the parallelogram formed by uniting the bases of the two larger, each outer wall and buttress occupy two, or the two walls and their buttresses four of the twelve divisions, leaving eight for the space between them.

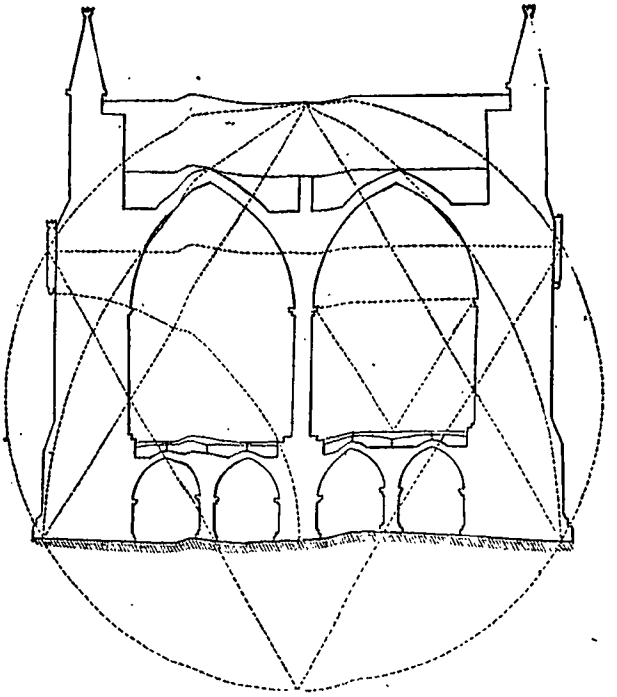


Fig. 3007. CHAPTER-HOUSE AT WELLS.

Where it is determined that the walls shall occupy one-third of the section of a building, no figure is so well calculated for such a distribution as the equilateral triangle; it enables the architect at once to limit and fix the proportions of his design; hence its universal application: and the mysterious qualities attached to it by the freemasons no doubt arose from the extraordinary facility it afforded them in setting out their several works. What can be more simple or more beautiful than the distribution of this edifice? Within a circle a hexagon is set out, the perpendicular sides of which mark the outer faces of the buttresses; the junctions of the angles, by forming a base to every two sides, produce the two equilateral triangles, which sub-divided not only enable us to arrange the other portions accurately, but also to measure with the greatest nicety their relative dimensions. The quantities of material employed in construction can be estimated by such means much more easily than by measuring each portion separately, cubing it, and adding the numerous dimensions so obtained together; there is decidedly more simplicity in the former than in the latter system: the area of one triangle being found, we at once know that of all the rest,

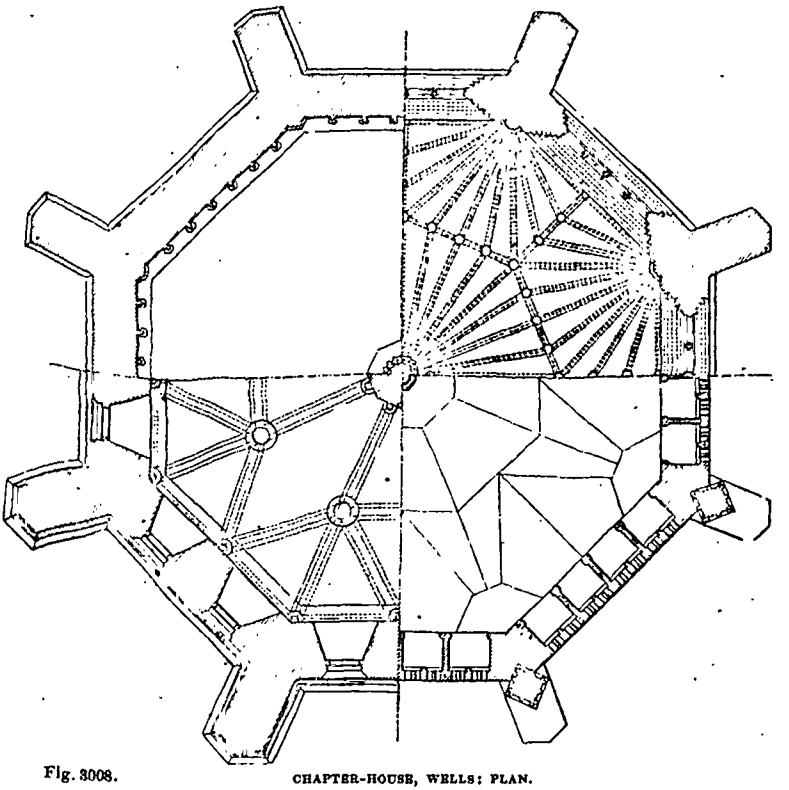


Fig. 3008. CHAPTER-HOUSE, WELLS: PLAN.

or of any portion. In the subject before us the distance from the middle of one buttress to that of the other is 31 feet 6 inches, and the diameter taken through them at this level is 92 feet; omitting the buttresses, the outer side measures 26 feet, and the inner 21 feet 6 inches, the respective radii of the circles which comprise the octangular outer walls and the void being 38 feet and 31 feet 5 inches. Hence we find that the entire area of the

building without the buttress is - - - - -	3264 feet.
The area of the void - - - - - -	2176 feet.
And of the walls or points of support - - - -	1088 feet.

At the level of the crypt, above the outer plinth, we have these regular proportions, two-thirds void and one-third walls.

The height of the entire building, from the pavement to the top of the parapet, is 72 feet 6 inches, and to the top of the pinnacles 92 feet, the total height being equal to the extreme diameter taken above the plinth moulding on the outside. The interior of this chapter-

house exhibits the most perfect proportions as well as appropriate decorations; the eight windows, divided into four days, have their heads filled in with circles set out upon equilateral triangles; the vaulted stone roof rests partly upon the octangular central pillars, 3 feet in diameter, surrounded by sixteen small columns, one at each angle and another between; the height of the pillar is 22 feet 8 inches.

Thoroughly to comprehend the expression, as well as use of the various members found in the architecture of the middle ages, we must trace the progress made in vaulting, and observe the changes it underwent, from the simple cylindrical to the more complex and difficult display of fan tracery or conoidal arches. The ridge ribs, or *liernes*, as they are termed, in the crypt of the Chapter-house at Wells, pass from the centre of the building to the middle of each buttress; the diagonals, or *croissées*, mitre into them as well as into the *formerets* or ribs against the outer walls.

In the vaulting of the Chapter-room, we have evidence of greater refinement, and an

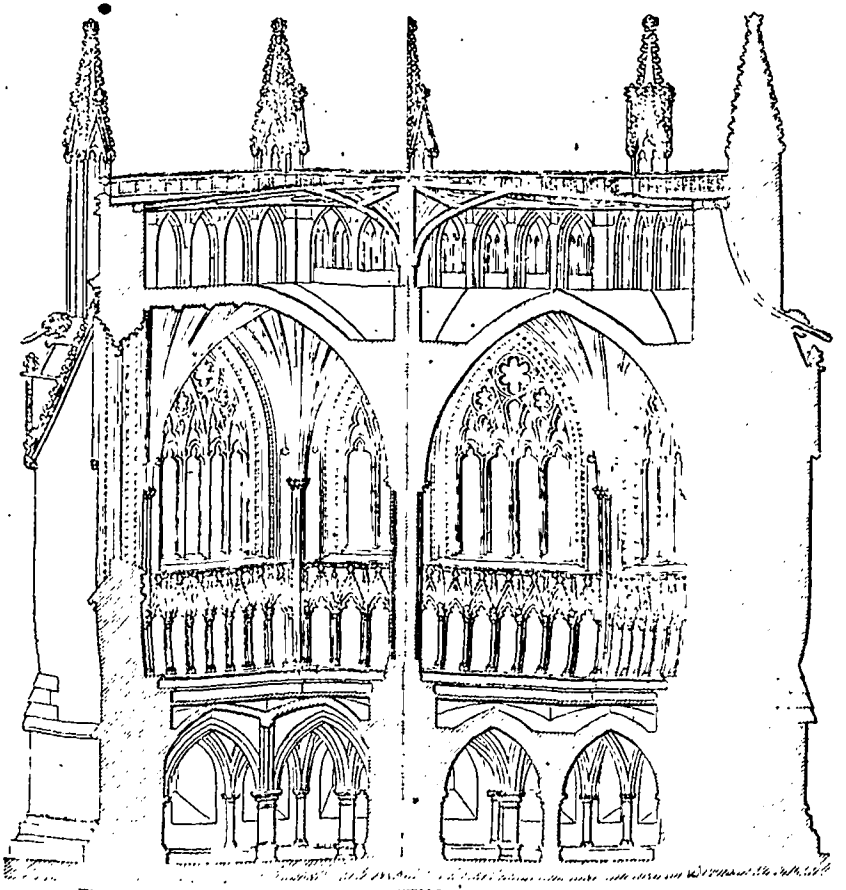


Fig. 3009. CHAPTER-HOUSE AT WELLS: SECTION.

improvement in the decoration, by the addition of a number of intermediate ribs terminating against the octangular one in the middle.

At a later period we find transverse ribs made use of, then others between; but although the design may seem complicated, yet when laid down the plan will assume the greatest simplicity, as shown in the division representing the groining of the crypt.

When this system had been carried out to a considerable extent, the fan tracery was introduced, and although apparently more difficult of execution, it is far more scientific in its application and arrangement, evincing a higher knowledge of mathematical principles and geometry, and is another evidence of the gradual progress of the mind towards perfection in this style of architecture.

Westminster Abbey, commenced in the year 1245, is in that style which for many years prevailed in France: the fine church at St. Denys, near Paris, is exactly similar in all its detail. The windows are wide, divided by mullions, and have their heads filled in with plain circles, the origin of the cusp, or that kind of decoration which every pointed arch afterwards received. This style, which succeeded the Lancet, is found throughout England, and many of the parish churches exhibit fine examples of it. Stone Church, in Kent, of which the writer has published an account, may be cited as one of the best; its ornament shows the skill and taste that prevailed among the freemasons at that period. Salisbury, Wells, and York Cathedrals abound with rich foliage and sculptures of the highest merit executed at the same time, and it is wonderful to observe to what a state of perfection the artists of this country had arrived. The effects of the chisel of the Pisan school were displayed upon marble, but our sculptors worked upon an inferior material; yet the draperies of their figures, as seen in the front at Wells, and elsewhere, are quite equal to those wrought by the pupils of Italian masters at the same time. The circle and its intersections at this period were alone employed for the plans of piers, sections of mouldings, and the filling in of windows and doorways: from them we trace the origin of the style which immediately succeeded.

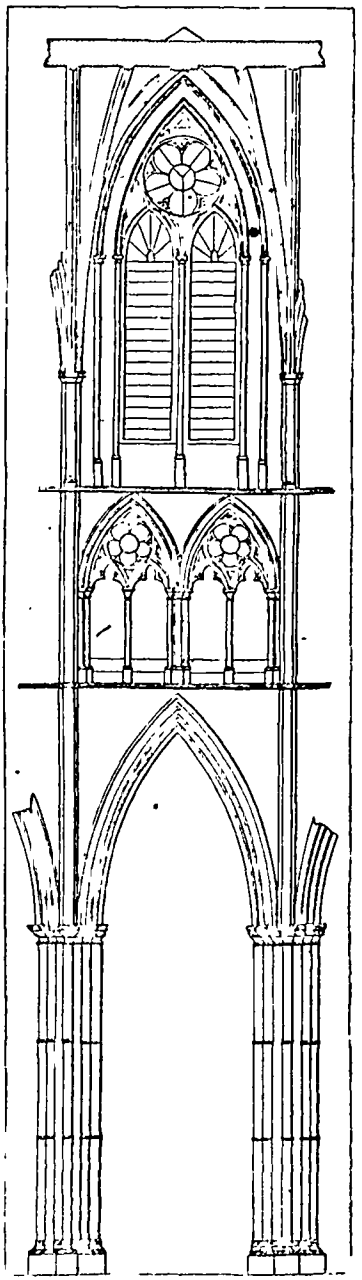


Fig. 3010. WESTMINSTER ABBEY.

The cathedrals of Cologne, Amiens, Beauvais, the Sainte Chapelle at Paris, and numerous other examples on the continent, exhibit the same proportions and style with that of Westminster; the lofty pointed arches, which rest upon the main cluster, are decorated with numerous small mouldings; the triforium, in some instances glazed, have their pointed arches filled in with trefoils, cinquefoils, or sexfoils, and the clerestory, carried up to the very apex of the vaulting, is similarly adorned. Westminster Abbey is one of the finest examples of building executed in the thirteenth century.

Tracery and Geometric Forms.—To comprehend thoroughly the principles which directed the freemasons of the middle ages in the execution of all their works would require far greater illustration than can be bestowed upon the subject in the present volume: it must be sufficient if we point out a few which influenced the design of some of their best examples, and show that it is a perfectly erroneous opinion to suppose they were executed without a thorough knowledge of certain rules, originating with themselves, and perfected by a constant study of what was not only useful, but productive of the best effect. Those who inquire into this subject must collect the data upon which an opinion can be formed, for it is scarcely possible, without positive measurement, to arrive at any conclusion upon the matter: the admirer of the Greek, or the commentator upon Vitruvius, alone can scarcely hope to be successful: it is true that in one of the early printed Italian editions of the valuable author quoted, there are several diagrams which seem to point to the subject, but the student will find only the nucleus around which the lovers of geometry in the middle ages arranged their varying and beautiful forms; this is the equilateral triangle, and by inclosing the plan, section, or elevation of a building within it, the several proportions can be accurately measured, and if sub-divided into a number, either of the triangles would show the proportion it bore to the whole area.

In one of the tracery heads of the windows in the cloister at Westminster, the date of which is about 1348, we have two figures that resemble the plans given to clustered pillars, indicating at once that the same principles were applied to the setting out of both windows and points of support. When the circumference of a circle is divided into twelve equal parts, the points which divide them form the termination of four equilateral triangles, and we have at their intersections, not only the centres of the circles that constitute the filling in, but also the several mitres and other portions of the figure.

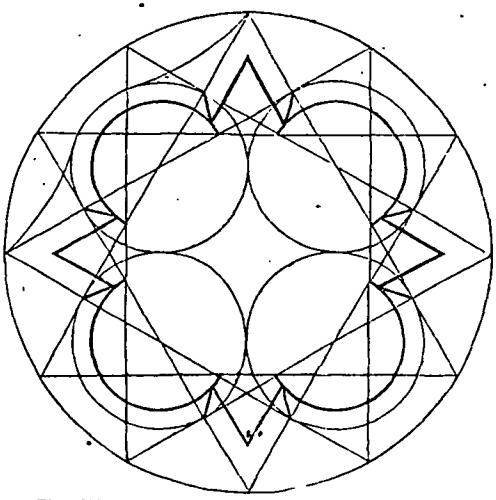


Fig. 3011. CLOISTERS AT WESTMINSTER ABBEY.

These rules were evidently applied to windows, and to tracery of every description, executed at the end of the thirteenth and commencement of the fourteenth centuries; also to the plans of the main cluster of pillars in many cathedrals and churches. For nearly a century, circles and their intersections formed the ornamental portions of every kind of panel and window head; they were afterwards blended into other figures, and apparently set out upon different principles; but the hexagon and equilateral triangles were necessary to produce the flowing lines which succeeded. The change which took place in design no doubt arose from the facility which had been attained by the practice of this method, and if it were possible to exhibit each variety in England alone, there would be ample evidence of the inventive power of the freemasons, and the progressive improvement in their school for depicting form. The quatrefoil in fig. 3011. is met with in the panels of several altar tombs, in the spandrills of the arches of doorways, and it is worthy of observation that all the mitres, where the figures change their form, are perfect for each: had these considerations been neglected, we should not have had the graceful flowing lines found in these designs: no other triangles crossing are so universally applicable, or require less skill in their adoption. The student of the present day might occupy a life in the collection of these subjects, and they are most excellent models for the application of the rules of theoretical geometry to practice.

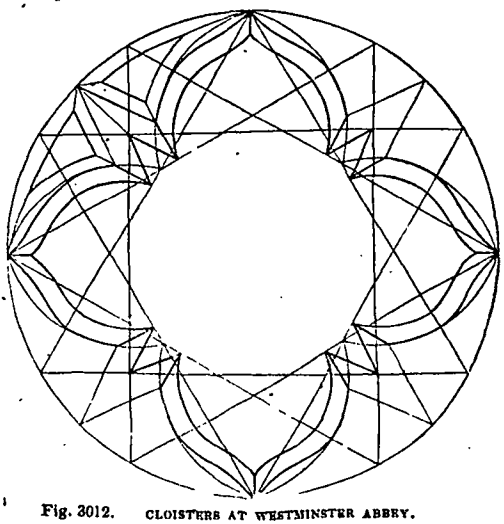


Fig. 3012. CLOISTERS AT WESTMINSTER ABBEY.

Windows of three Days or Divisions are met with, having heads of singular beauty, inclosed within an equilateral triangle, and so numerous are the designs, that it is rare to meet with two exactly similar. In

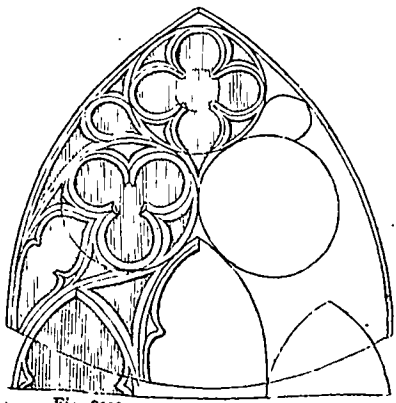


Fig. 3013.

the more simple of three days or lower divisions, the head is occupied by three circles, each of which contains a trefoil constructed upon the crossing of either three or four equilateral triangles.

A very extraordinary design, composed of intersecting circles, is to be seen at the east end of the chancel of the church at Sutton, at Hone, in Kent; although much dilapidated, it still preserves many of its original flowing lines, all struck from the same radius, through points previously determined by crossing the primitive circle by four equilateral triangles.

At half the height of the head of the window a horizontal line may be supposed to be drawn from one side to the other, on which are three circles: the two outer touching, are crossed by the third, struck from the point of their junction; with the same radius several spherical triangles are struck from the points of intersections, producing the lines, which unite and divide the window head into several compartments, differing in pattern and dimension. After the circles were struck, the lines that did not play into each other were left out, and those only retained which flowed on gracefully; by these nice considerations and just application of principles, the masons were certain of producing a perfect effect, without rigidly adhering to any particular form.

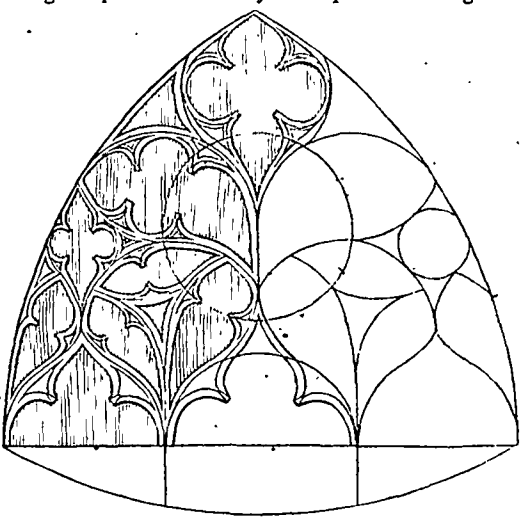


Fig. 3014. SECTION AT HONE, KENT.

Windows of four Days or Divisions. — Among the heads of a more simple character are those which contain one large circle, subdivided by three equilateral triangles, each

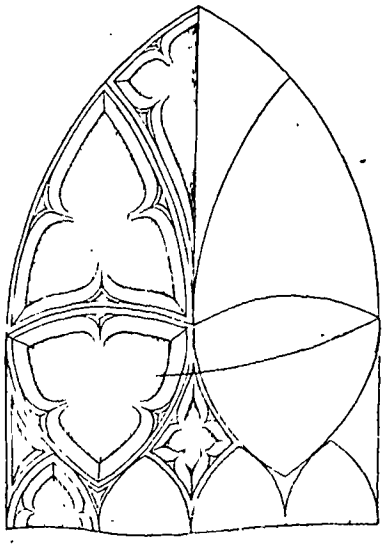


Fig. 3015.

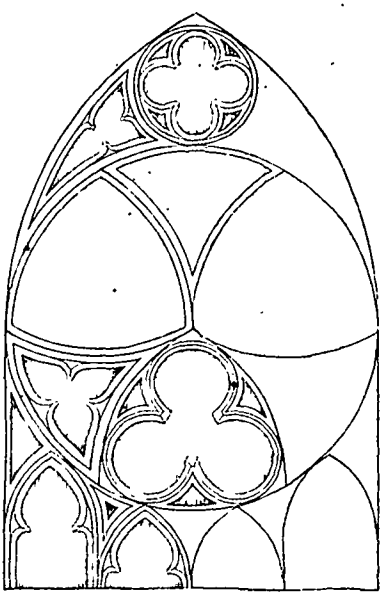


Fig. 3016.

inclosing a trefoil. Others contain, in addition to the one great equilateral triangle, two smaller, constructed upon the points of its base, and dropping into the space comprised between the heads of the divisions below.

Windows of Six Divisions are far more complicated, and, though exhibiting greater skill in geometry, are set out precisely upon the same principle. The two equilateral triangles inclosed within the great circle mark out the prominent features of the design, and their terminations are the centres of as many spherical triangles, which, by their crossing, constitute the elaborate filling in.

In some examples, above the two main lower divisions is a circle divided by several others, the twelve which are indicated in the figure serving to proportion the tracery of this compartment.

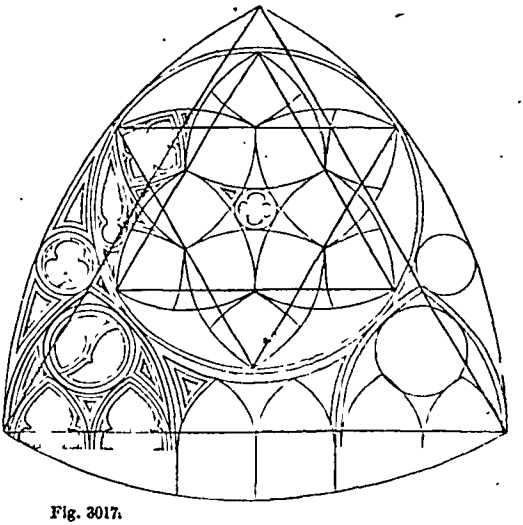


Fig. 3017.

At the latter end of the fourteenth century, these designs were so multiplied that almost every cathedral and church had its peculiar windows: in Amiens cathedral, the chapels constructed at this same time receive their light from windows, the heads of which are filled in with tracery exceedingly varied, but the general principles of setting out the work are preserved; the circle and the equilateral triangle were subdivided almost to infinity, and at no period of the arts do the inventive faculties appear so fertile as in that we are now considering. The great west window of York Cathedral is the finest example of the improvement made in this mode of decoration; the geometric forms are there so concealed by the blending of the several curves, as to produce continued flowing lines, which is partly shown in fig. 3014.: they are, however, all set out in the same manner, and the centres upon which they are struck are established by the crossing of equilateral triangles.

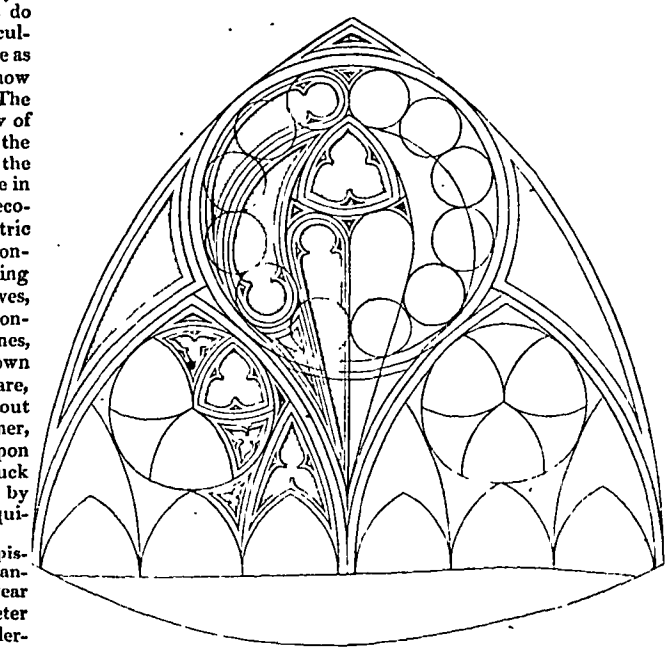


Fig. 3018.

During the episcopacy of John Grandisson, from the year 1327 to 1369, Exeter Cathedral was undergoing an entire change in its architecture. To this bishop we are indebted for the great west window, of nine days, and several smaller of four and five, in which are introduced tracery showing a great variety of design: some are composed of equilateral triangles, each containing a trefoil, some of circles with six turns, others have four and three; but the heads of all, varied as they are, belong to the same school as fig. 3017.

The great east window at Bristol Cathedral is another fine example of nine days,

executed about the middle of the fourteenth century; the centre of the head of the window, or rather the nucleus to the tracery, is an octagon, six sides of which are retained, the other two being suppressed, to allow of a better combination with the three centre divisions of the lower part.

The equilateral triangle also defined the form and magnitude of the several mullions, as shown by the diagram, constructed upon measurement of the windows of the clerestory of the nave at Winchester: a line drawn from the apex of one mullion to the other is the base of the triangle, and the space inclosed by the two is divided into ten other equilateral triangles, two of which agree in dimensions and form with each mullion. Of the twelve equilateral triangles embracing two half mullions, ten are given to the day or space to admit the light, and two, or one-sixth of the whole, is comprised by the mullion; such appears to have been the manner of proportioning the parts of windows in the middle ages.

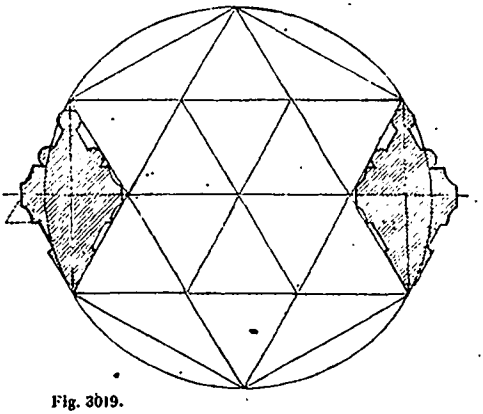


Fig. 3019.

Rose Windows in the West Transept of the Church of St. Ouen at Rouen is 29 feet 6 inches in diameter, and composed of seven equal circles, one of which occupies the centre: each of those, which surround it, are again subdivided by others; two only of the outer six are preserved in the figure, and form the quatrefoils, whilst the intersections of the others serve as centres to the rest of the design.

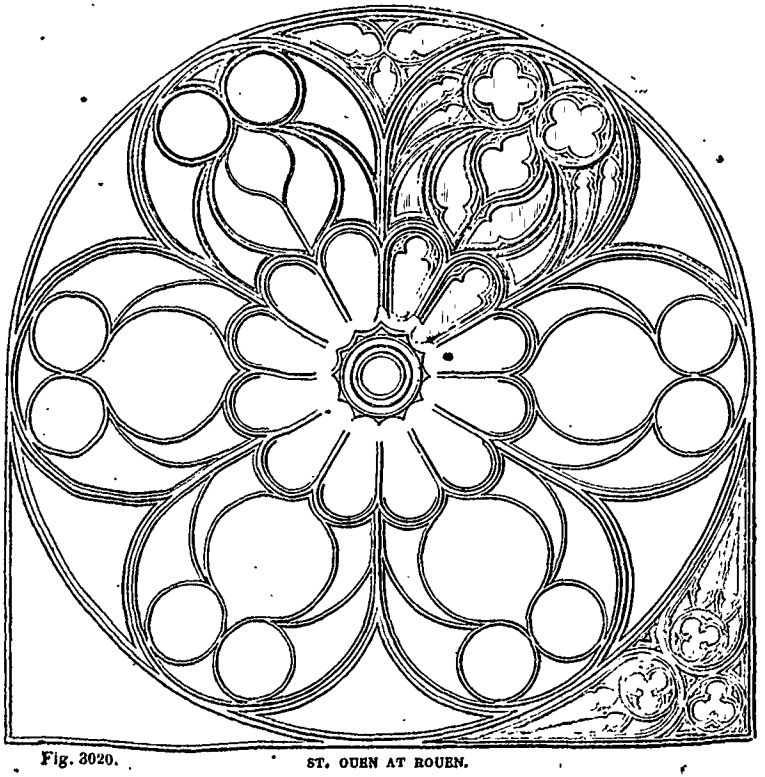


Fig. 3020. ST. OUEN AT ROUEN.

Rose Window of the South Transept of the Cathedral at Rouen is 23 feet in diameter, measured to the centre of the large bead, which comprises the figure. A portion only of

this beautiful example is given, for the purpose of exhibiting the principle upon which it is set out: it will be evident that the nucleus of the design is composed of two equilateral triangles, and the sides of each continued, constitute the alternate divisions.

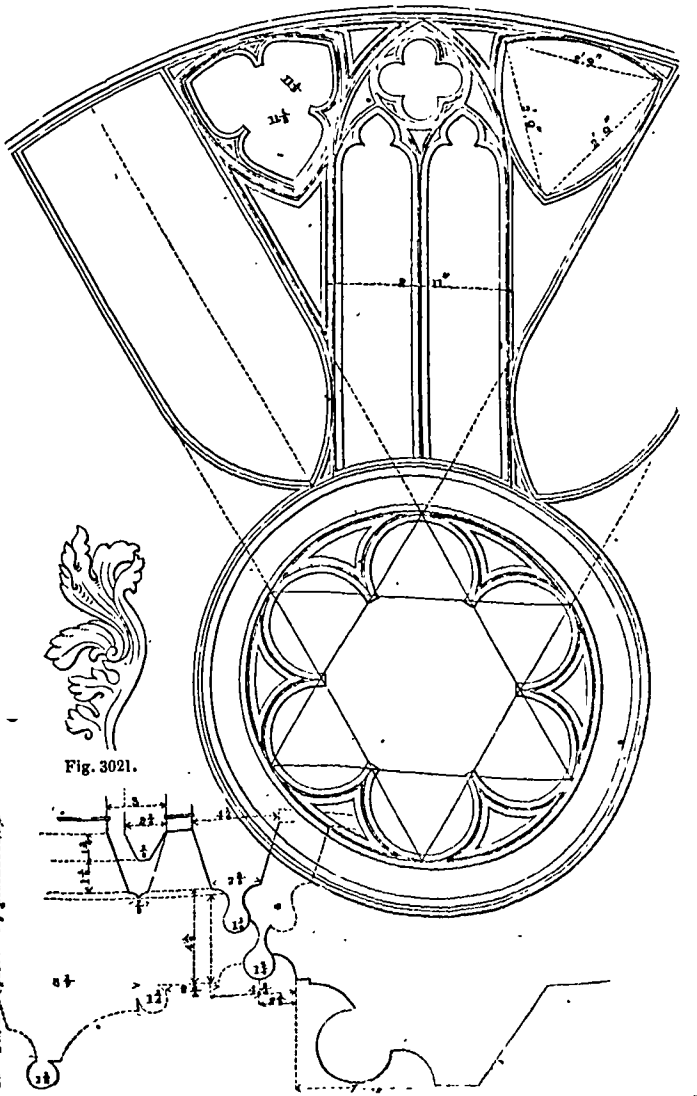


Fig. 3021.

Fig. 3022. ROUEN CATHEDRAL: SOUTH TRANSEPT.

The internal hexagon has its parallel sides prolonged, to mark the position of the four divisions that have their pointed heads attached to the small circle, which forms the eye of the pattern; and the length of these prolonged lines is limited to the extent of the sides of an equilateral triangle, which is again divided regularly, the triangular spaces between being filled in with trefoils. The small mullions are in width 2½ inches, the next size 3 inches, and those which mark out the figure and have a bead for their termination are 4½ inches: another bead and bold projecting label, or rim, circumscribe the whole rose window, the hollow around which is enriched with a curved leaf. On each side of the internal hexagon an equilateral triangle is constructed, around which a circle is struck, uniting elegantly with the next, and forming the six turns which characterise the filling in of

circles at this period; these were the principal decorations after the Lancet style was abandoned, and were continued until succeeded by more flowing and varied designs.

Rose Window of the South Transept at Beauvais, 34 feet 4 inches in diameter, is composed of six large circles and their intersections.

To set out this window, the great circle expressed by the outer bead is divided into twelve parts, each being equal to half the radius; twelve equilateral triangles are then inscribed, the points of which touch each of the divisions, and where they cross nearest to the outer circle, the twelve pointed arches that surround the figure are struck; the other points of intersection of the triangles are centres, from which the other curves are drawn. It must at once be evident, that in a circle so divided, or by any other equal number of equilateral triangles, the portions contained between the smaller angles must be equal to each other; the six circles around the centre have their curves blended into the outer, and if it be required to fix centres for each of these flowing lines, they can only be obtained by covering the entire rose window with lines in the manner already described. The radius being equal to the side of a hexagon, and that figure being composed of two equilateral triangles, was probably the chief reason of its first preference over all others; it certainly affords the most extraordinary powers of combination, and there is scarcely a moulding or form in the architecture of this period but is set out from it. The mullions that bound the divisions are all portions of this figure, as are the mouldings, which sweep round the arches of the buildings themselves. Nothing can surpass the brilliant effect of these marigold windows when glazed with rich colours, and exposed to either a rising or setting sun; in the example now described, this effect is still further heightened by making nearly the whole end of the southern transept a continuation of the same design, the glass descending almost to the tops of the doors which afford access to the cathedral. The construction of such works must excite our highest admiration, for it appears scarcely possible to excel the perfect manner in which the parts are put together and worked off, the execution being in every particular worthy the design.

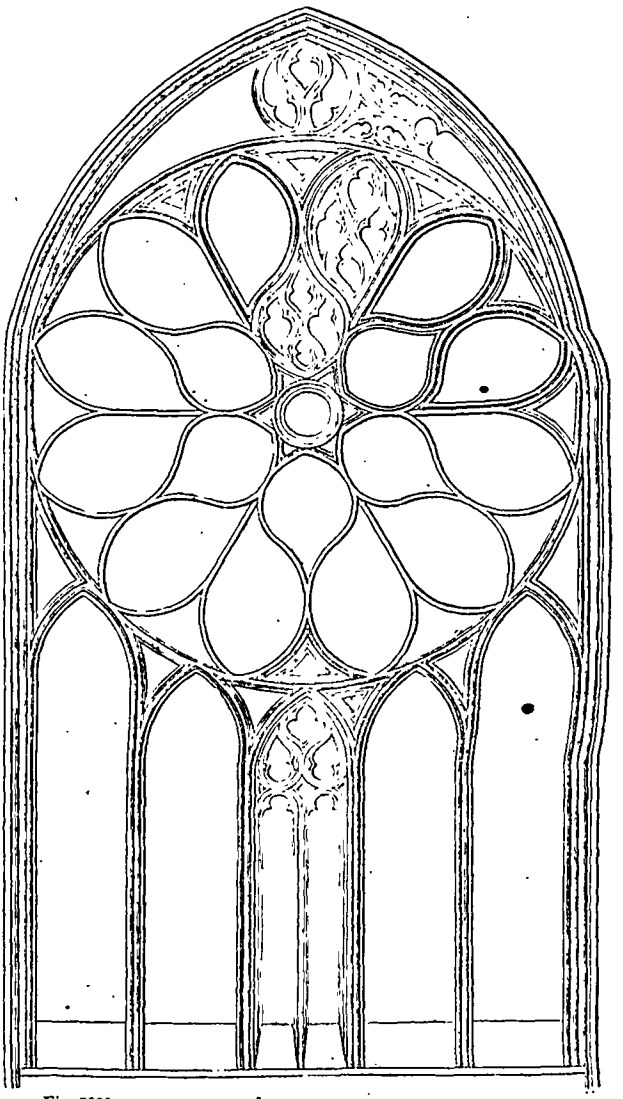


Fig. 3023. BEAUVAIS CATHEDRAL: SOUTH TRANSEPT.

The Rose Window in the South Transept at Amiens, 29 feet 6 inches in diameter, is set out upon two squares, which cross each other diagonally.

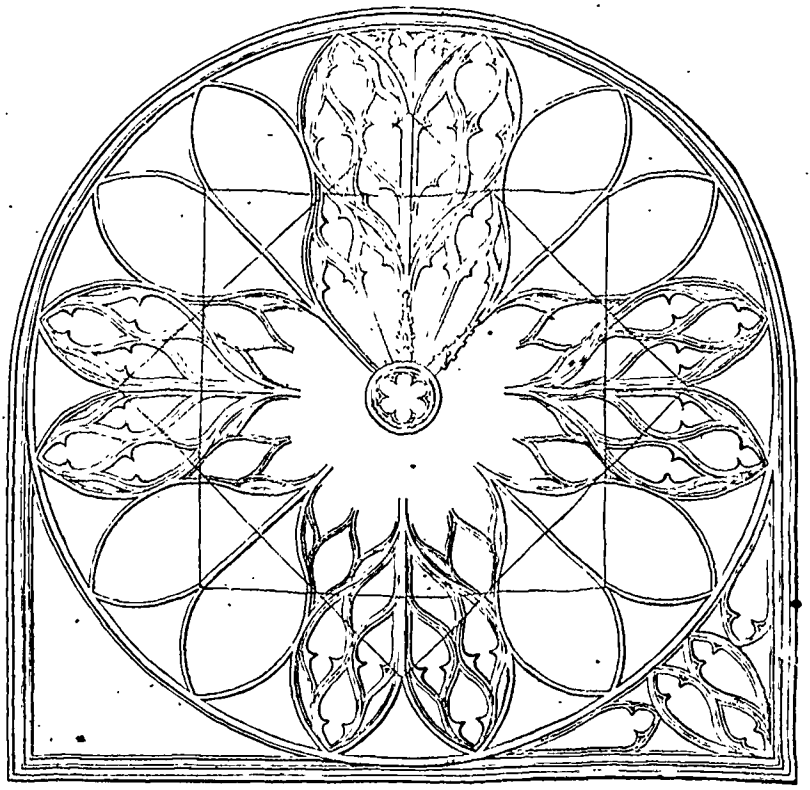


Fig. 3024. AMIENS CATHEDRAL : SOUTH TRANSEPT.

Sixteen divisions are employed in this figure, and by crossing as many squares, we arrive at the method by which it is set out; each side of the square is equal to the radius by which the master line on the outer bead or circle is struck: where the squares cross each other are the divisions of the pattern, and their several points are the centres upon which the pointed arches are struck, which surround the outer portion of the rose.

Where the lines of the squares cross, in the interior of the figure, the smaller divisions are established, and their points of intersection serve for centres to strike the lesser curves; to show this clearly the whole must be set out, and drawn to a large scale.

The architecture of France underwent a material change after the thirteenth century; the heads of the windows were no longer filled with tracery composed of six foils, generally three in each window, but branched out into a more running pattern, as practised in several parts of England. The fourteenth century not only exhibits windows of more difficult design, but an apparent absence of the principles by which the several parts were proportioned to each other. Before the Perpendicular style appeared, great progress had been made in the groining of the spacious vaults of the naves, as well as those of the side aisles. After the fan tracery was substituted in England, the windows had straight mullions ascending till they intersected the arch; and we have no further display of the varied figures that everywhere prevailed before: geometry was now exercised upon the intricacies which their surprising vaults exhibited. It is somewhat singular that we never find the beauties of a previous era retained, and blended with that which succeeded.

For the 300 years during which the Pointed style continued to flourish, each half century gave to it a new character; hence we have seldom any difficulty in establishing its date: all these changes resulted from an improved knowledge in the art of construction. The lodges of freemasons were gradually approaching the principles which directed the efforts of the architects of the Byzantine school, and which were found too refined and delicate to be practised out of Italy after the eleventh century.

The Rose Window in the Northern Transept of the Church of St. Ouen at Rouen, 28 feet 6 inches in diameter, is an example of the pentagonal setting out.

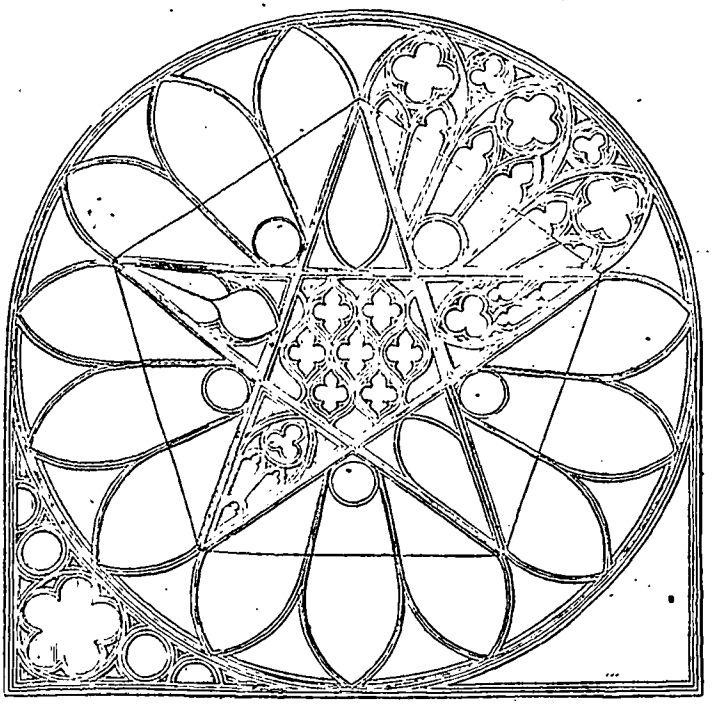


Fig. 3025. ST. OUEN AT ROUEN.

When the sides of a pentagon are prolonged, they unite and form five isosceles triangles, each having for its base a side of the original pentagon. The equilateral triangle, the square, and the pentagon may have been adopted by different confraternities of freemasons; the first can be formed into hexagons, duodecagons and their multiples; the squares, by crossing diagonally, into octagons; they may be also tripled and quadrupled: the mitre of the equilateral triangle is in the direction of its centre of gravity, as is that of the square and the isosceles triangles; consequently to unite the mouldings around either, the plummet would indicate the direction of the line, when dropped from the angles and suffered to cross, the point of intersection being the centre of gravity common to the several lines.

In the chapel of St. Cecile is the monument of Alexander Berneval, the master mason of the works at St. Ouen, at the time the rose window was executed by his pupil, whom it is reported he murdered from jealousy: such an application of triangles was then called the *pentalpha*.

The foundations of this church were laid by Mardargent, about 1318, by whom it was built as far as the transept; but probably the rose window of the northern transept was not inserted till many years after, for the memorial of Berneval bears the date of 1440: this monumental stone is 8 feet 6 inches in length, and 4 feet in width, and in it is represented the architect and his pupil, each employed tracing with his compasses his respective design; these beautiful brasses with their rich tabernacle work were in the highest state of perfection when the writer was last at Rouen, and around the master figure was inscribed in German letters: —

Cy gist Maistre Alexandre de Berneval, Maistre des oeuvres de Maconnerie du Roy, notre Sire, du Baillage de Rouen, et de ceste Eglise, qui trespaya, l'an de grace mil. cccc.xl. le v.e jour de Jaunier.

Prie's Dieu pour l'ame de luy.

The date of the pupil's death is not commemorated, which has led some to imagine the tale of his murder untrue, and that he erected the monument to his master with the intention of being buried by his side.

The North Rose Window at Amiens, 37 feet 8 inches in diameter, is a magnificent example of the application of the pentagon, with 5 isosceles triangles around it.

This window, probably executed in the fourteenth century, has a great resemblance to the last described; the fan tracery, of which we have early specimens in the cloisters at Gloucester, required the same knowledge of geometry to perfect their design. In 1482 Euclid was first printed at Venice from the Greek text; but geometry had been studied in England from the time that Adhelard, in 1130, had introduced a translation of that author from the Arabic versions which he met with during his travels in Spain. In 1256 Campanus of Navarre translated Euclid, who seems to have been commented upon by several eminent writers, and no doubt it was the text-book of the freemasons, who diligently applied the problems it contained to every purpose of their art. In 1486 the Editio Princeps of Vitruvius appeared, and the commentaries of Cæsare Cæsariano followed in 1521; the latter author published three plates of the Cathedral at Milan, covered with equilateral triangles, which have not been described so as to be useful or understood. The compartments which have the flat sides of the original pentagon for their base, and parallel sides throughout till they terminate in the pointed arch, have their mullions proportioned to their opening, the larger being double the size of the smaller, whilst the latter are equal to half the open space between them: the mullions in these examples, which divide two spaces, 6 inches in width, are usually 3 inches in thickness, and the others are in the same proportion. The next sized mullion is 4½ inches, with a bead of 1½ inch diameter, which runs round the whole pattern of the figure, the centre of which may be called the master line, by which all the rest are set out; the several mullions are all twice as much in depth as in width.

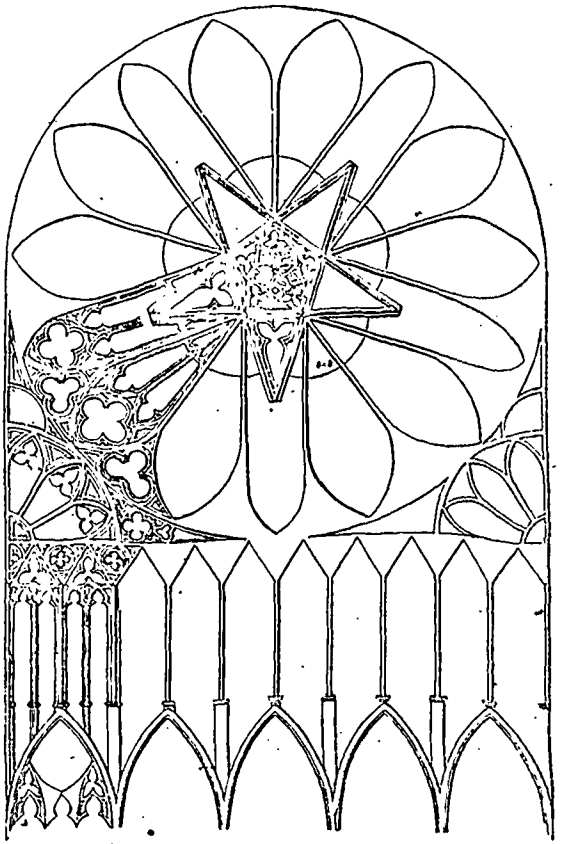


Fig. 3026. AMIENS: ROSE WINDOW.

Baptistery of Pisa. — The internal diameter of this circular building is 100 feet, and the thickness of its outer walls and columns 10 feet 6 inches; its external diameter is 121 feet, the area of which is 11,499 superficial feet, that of the interior being 7854; if we deduct from it what is occupied by the four piers and eight columns, or 188 feet, we have 7666 feet for the void, exactly two-thirds of the entire area. To find these proportions in an edifice commenced about the middle of the twelfth century in Italy, is a curious corroboration of the opinions already advanced, the same rules as those described for the Chapter House at Wells being apparently followed: the conical brick dome was the work of an after period, and may have been the prototype for that of St. Paul's at London; the pointed architecture belonging to the exterior of this edifice, of the same character as that which adorns the crosses of Queen Eleanor in England, was added in the fourteenth century.

The section shows how the equilateral triangle governs the proportions of this celebrated building; the extreme diameter is the base, and its apex the level on which the

more recent conical and hemispherical domes are placed: the intersection of the two great triangles fixes the diameter to be given to the internal void, around which the side aisle, its walls and pillars should be formed. The circle which has its diameter comprised between the apex of the two equilaterals determines the clear width between the

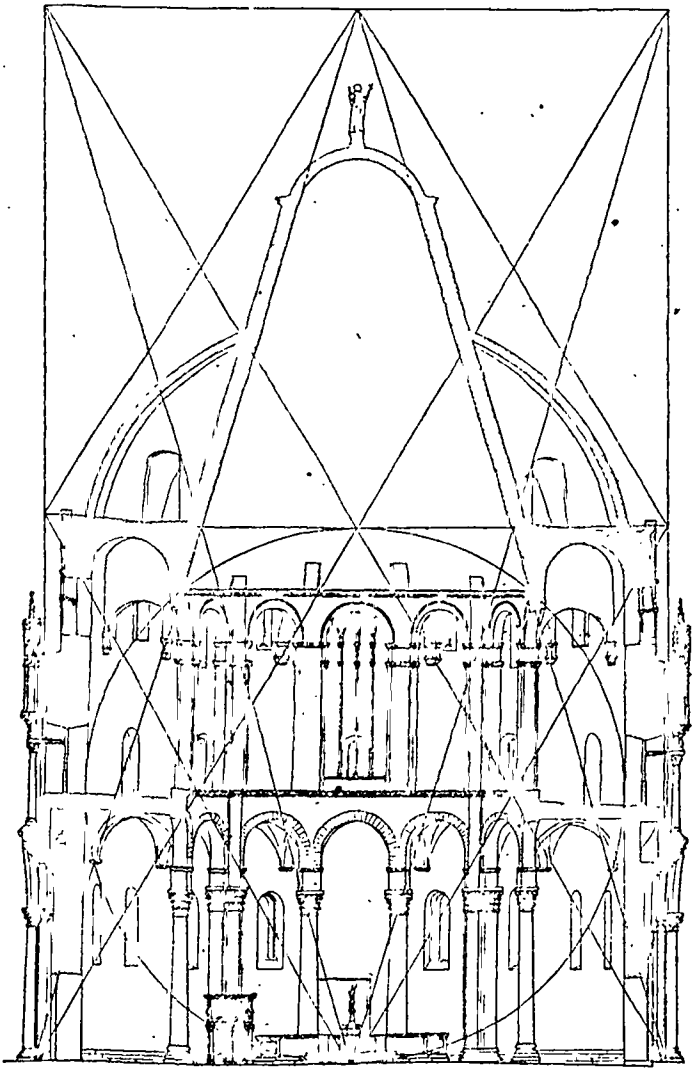


Fig. 3027. BAPTISTERY OF PISA.

outer walls. That the architects of those days delighted in the forms produced by the several intersections of the circle in combination with the equilateral triangle, we are assured by viewing the several designs they have left us in mosaic upon the walls of the Duomo, and at the cathedrals of Florence, Sienna, and elsewhere.

Roslyn Chapel, Scotland, commenced about the year 1446, has its buttresses well suited to give aid to the walls, and to enable them to resist the thrust of its nearly semicircular vault, which they receive below the springing. The extreme width from face to face of the buttresses is 48 feet 4 inches; the span of the nave is 15 feet 8 inches, being 5 inches less than the proportion of a third; the two side aisles together

are 15 feet, or within a few inches of the width of the nave; consequently the walls and piers in this beautiful example are 17 feet 8 inches, or 15 inches more in extent than they would have been if the proportion of one-third had been adopted. The height from the pavement to the under side of vault is 41 feet 10 inches.

After the examples described, we cannot doubt of the great proficiency that had been made in the application of the rules of geometry to architecture; every feature, whether the simple moulding or the most elaborate tracery, was set out either upon the equilateral triangle, square, or pentagon, and these regular figures seem to have been chosen on account of the facility by which they are subdivided. From the introduction of the style each fifty years that succeeded brought with them new and improved principles, and at the very commencement of the fourteenth century, we see the clustered pillar and

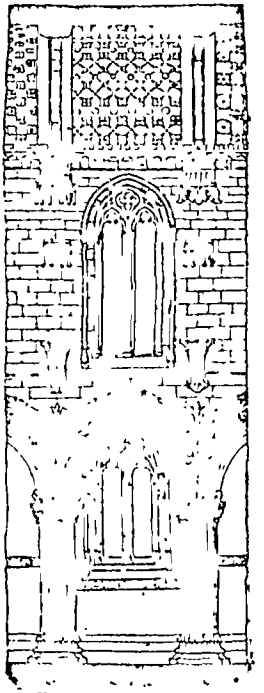


Fig. 3028. ROSLYN CHAPEL.

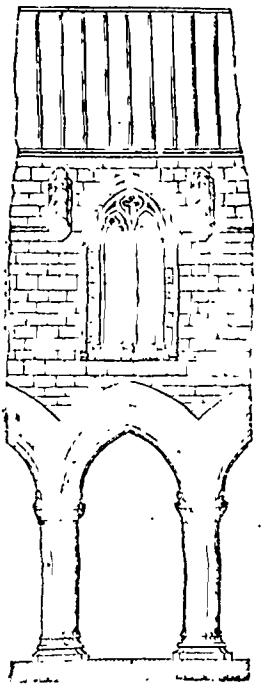


Fig. 3029.

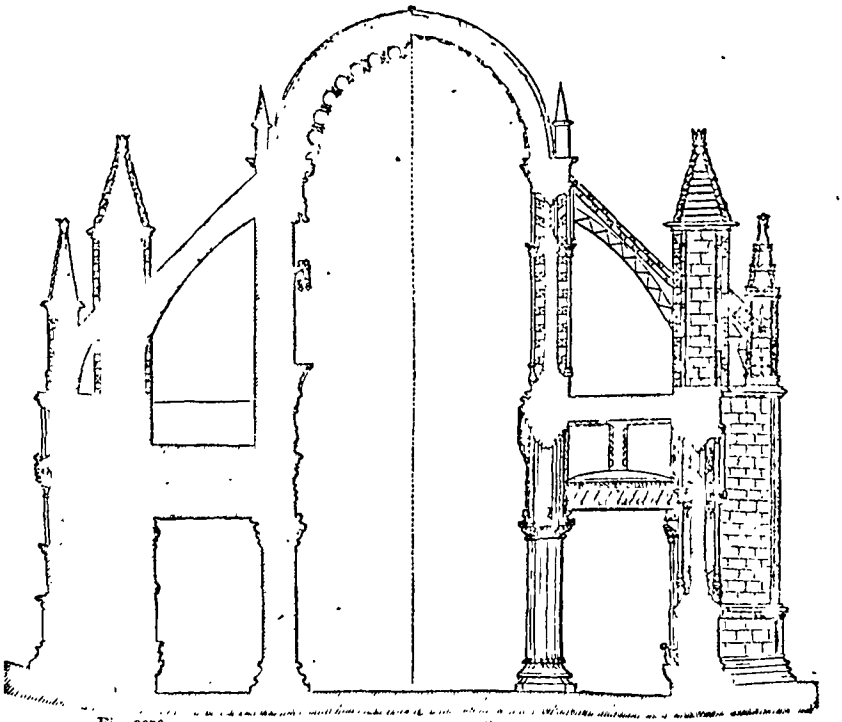


Fig. 3030. SECTION OF ROSLYN CHAPEL.

its many moulded arches yielding to a style that combined greater simplicity with a more thorough knowledge of construction, which will be evident upon an examination of St. Stephen's Chapel, Westminster, (now destroyed,) begun in 1348, the nave of Canterbury and Winchester Cathedrals, and several others. In these examples we have elegantly formed arches resting on well-proportioned piers, the mouldings of which so combine that they form a perfect figure, and show that the points of support were designed to carry all that is placed above them; the same contour of moulding that surrounds the pier performs its useful part in the upper portions of the building, constituting one entire whole. This style, simple as well as elegant, was executed by masons fully qualified to advance it to the greatest perfection, and deserves both our study and admiration.

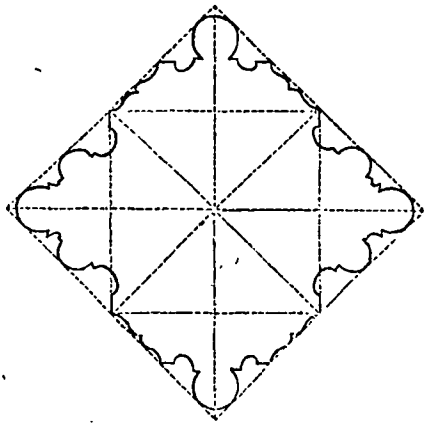


Fig. 3031. CANTERBURY CATHEDRAL.

Canterbury Cathedral exhibits every variety of style found in mediæval architecture; its history has been published by Mr. Britton: to that work, to which the writer contributed some measurements in 1820, he must refer for a detailed and elaborate account of the several changes made in the decoration of the edifice. It is only to the pillars of the nave we are desirous of drawing the attention, and that merely to show their simple form, and the manner of setting them out: four squares are so placed that their diagonals and sides are united in the centre, thus constituting a form capable of the greatest resistance at the four points of the entire pier, where the several thrusts and pressures are received: the O G mouldings of the piers run round the arches, whilst the columnar mouldings towards the aisle and nave support the ribs of their respective vaults. Greater simplicity can hardly be obtained, and every line and indentation of the plan has its use and appropriation: there is no profusion, or member for the sole purpose of decoration; in this arrangement we have the commencement of good taste, and the indication of a more harmonious and perfect style.

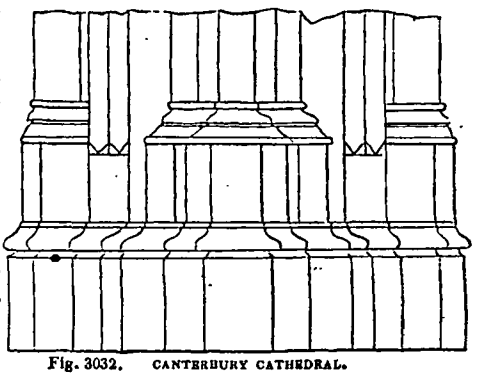


Fig. 3032. CANTERBURY CATHEDRAL.

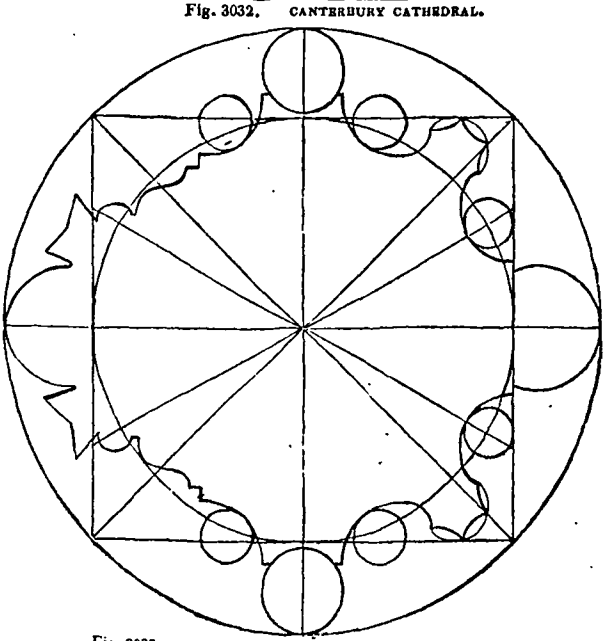


Fig. 3033. ST. OUEN AT ROUEN.

In the Church at St. Ouen at Rouen, we have a very different arrangement, and by no means so solid a form.

Winchester Cathedral.—One division of the nave has been selected to show the peculiar style practised at the latter end of the fourteenth century, and also the skill exhibited in changing the form of a Saxon edifice, and giving it its present character. The plan, fig. 3035., is that of the pillar, as well as of the mouldings and walls of the triforium and clerestory above. When William of Wykeham effected the changes in the nave of this cathedral, he preserved all above the arches of the triforium, cutting away only the masonry of each division below that level which intervened between the main pillars; he then caused the whole to be cased with an ashlar, so that the original Saxon masonry and proportions of the mass remain within the casing. The dotted semicircular arch is the same as that in fig. 2998., and in the roofs above the groining the Saxon walls are traceable,—another proof that when any alteration was made in a building by our mediæval masons, they did not think it necessary entirely to demolish it. We have in this example the decorative character which belongs to the architecture of the latter end of the fourteenth century, though somewhat heavy in its proportions, which arises from the mass constituting the original fabric being preserved, or having undergone so little change. The thickness of these pillars from north to south is 10 feet 8 inches, and from east to west 10 feet, whilst the width of the opening from east to west is only 14 feet.

If we examine the area of one severy of the nave, as left by Wykeham, and calculate the points of support, we shall see that the proportions are not those found in the nave at Canterbury, or in other cotemporary buildings; comprising the space between the buttresses, the entire area of the parallelogram contained between lines drawn through the middle of the piers from north to south is 2228 feet; while the points of support within that area are 557 feet, or one-quarter of the whole.

On the section, shown at fig. 3036., the buttresses on the north side project 6 feet; the north wall is 5 feet 6 inches in thickness, the half piers attached project internally 2 feet 1 inch; the north aisle is in width 13 feet 1 inch, the pier 10 feet 8 inches; the clear width of the nave 32 feet 5 inches; the pier 10 feet 8 inches; the south aisle 13 feet 1 inch, the half-pier which projects from the south wall 2 feet 1 inch, and the thickness of the south wall 7 feet 2 inches; there are no buttresses, as the cloister, now removed, served their purpose. The width from east to west, measured from the centres of the piers, being 22 feet 1 inch, and the width of

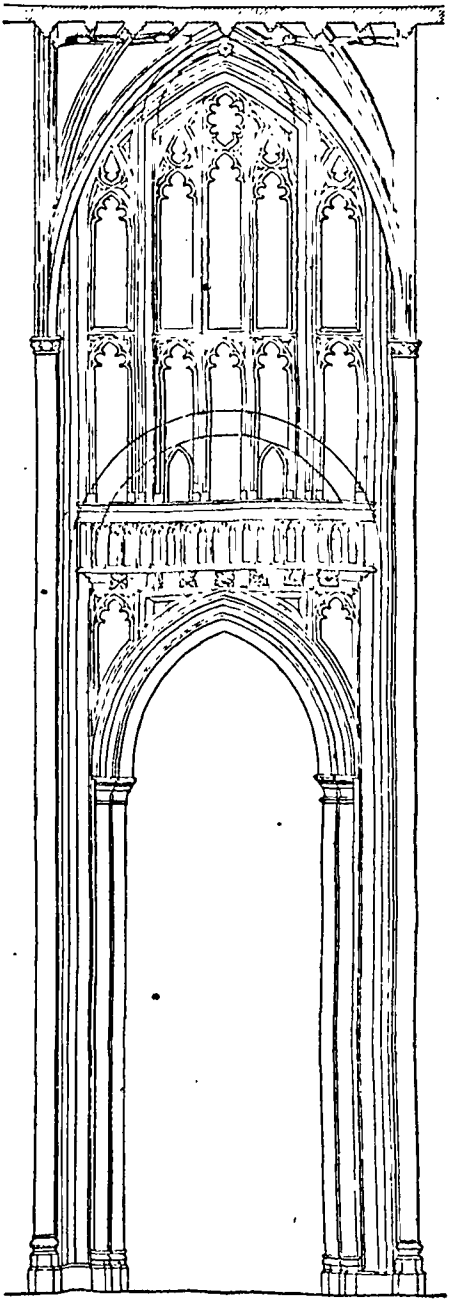


Fig. 3034. NAVE OF WINCHESTER CATHEDRAL.

buttresses outside 3 feet 2 inches. The cathedral or duomo at Pisa presents a very different result; the total width of the nave is 113 feet 6 inches, and the width of a severy 17 feet 1 inch, the area of which is nearly 1930 feet, the points of support being only a twelfth of that quantity on the plan, and one-sixth as regarded upon the section. Hence we see the necessity of ascertaining the proportions of mass and void in a building, before we can accurately judge of its merits as a style, each having its peculiar quantity, which marks its character.

The section or rather plan of the walls, on the level with the gallery of the triforium, shows the method adopted to proportion the openings to the mass. The thickness of the clerestory walls is included within the eight equilateral triangles, and where their sides cross, the position of the mullions is established. In fig. 3019. the circle which comprises the two that divide the window into three days shows their proportion and their size, which in this example is one-third of the opening: in a window of three days we have six triangles for space, and three for mullions: the splays at the sides of these windows, uniting them with the faces of the wall, are cut parallel with the sides of the several triangles. The main pier is set out by uniting the bases of two equilateral triangles with perpendicular lines, or forming the whole into the figure of a hexagon. By a comparison of this plan with that of fig. 2999., the additions made by William of Wykeham to the original Saxon pillar will be readily perceived.

The width of one of the divisions of the nave at Winchester, measured from the centres of the piers from west to east, is 22 feet 1 inch, and the same dimension taken in the nave at Canterbury is 20 feet only. In the former example the opening between the piers is 12 feet 1 inch, and in the latter 14 feet; there is consequently no comparison, with regard to lightness, in these two works of the same period; the pier being comprised $2\frac{2}{3}$ times in the entire division at Winchester, and $3\frac{1}{3}$ times at Canterbury, or on the pavement the plinths around the base seem to fall within one-third of the entire width. It would almost appear that in setting out the pillars of several cathedrals, the same system was practised as shown for the mullions of windows at fig. 3019.: but the plinths, and not the cluster of columns and mouldings, must be regarded as occupying the third. Bath Abbey church is 20 feet 2 inches from centre to centre of pier from east to

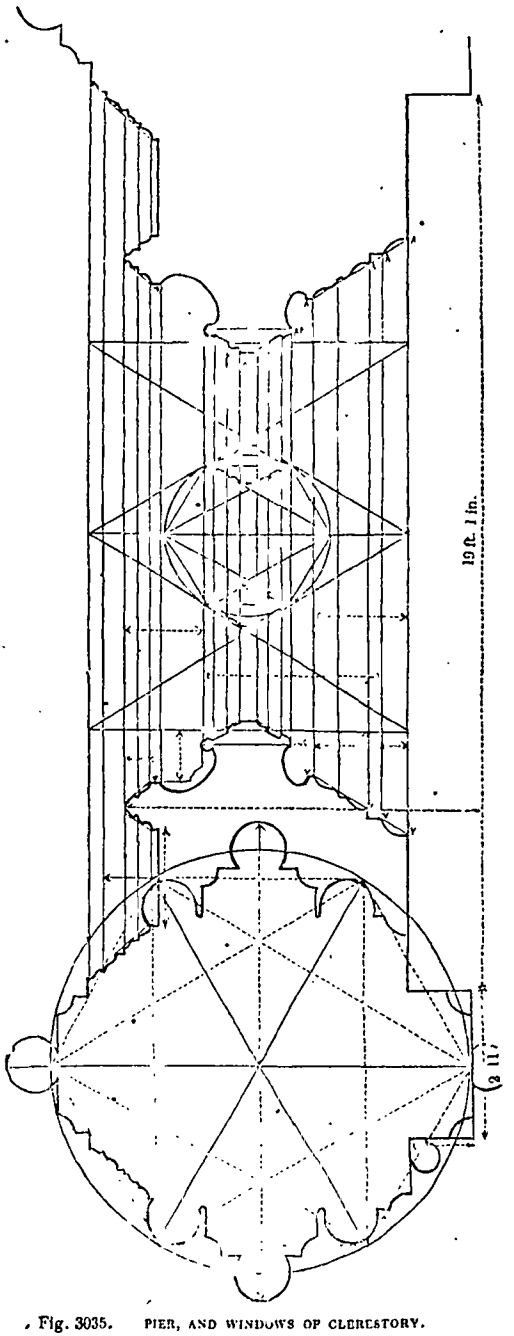


Fig. 3035. PIER, AND WINDOWS OF CLERESTORY.

west, and the clear width between the plinths about two-thirds of that dimension, and this is the case with many examples.

The Section through the Nave of Winchester Cathedral is highly deserving of our attention: the clear width of the side aisles is 18 feet 1 inch, and that of the nave 32 feet 5 inches; the clear width of the building between the outer walls is 80 feet, the thickness of the walls 16 feet 10 inches, the projection of the buttress 6 feet, and the thickness of the piers 10 feet 8 inches, making for the entire width from north to south 102 feet 8 inches.

The width between the walls forms the base of an equilateral triangle, the apex of which determines the height of the vaulting of the nave; a semicircle struck upon this base, with a radius of 52 feet, determines the intrados of the arches of the flying buttresses on each side, which are admirably placed to resist the thrust opposed to them.

On this section we have endeavoured to apply the principles of *Cæsare Cesariano*, before referred to, to the measurement of mass and void by a method far more simple than that usually adopted.

By covering the design with equilateral triangles we see the number occupied by the solids, and can draw a comparison with those that cover the voids: to prevent confusion in the diagram a portion only of three of the triangles has been subdivided, to show with what facility the quantities of the entire figure might be measured, if the several large equilaterals were subdivided throughout in a similar manner. The band which extends

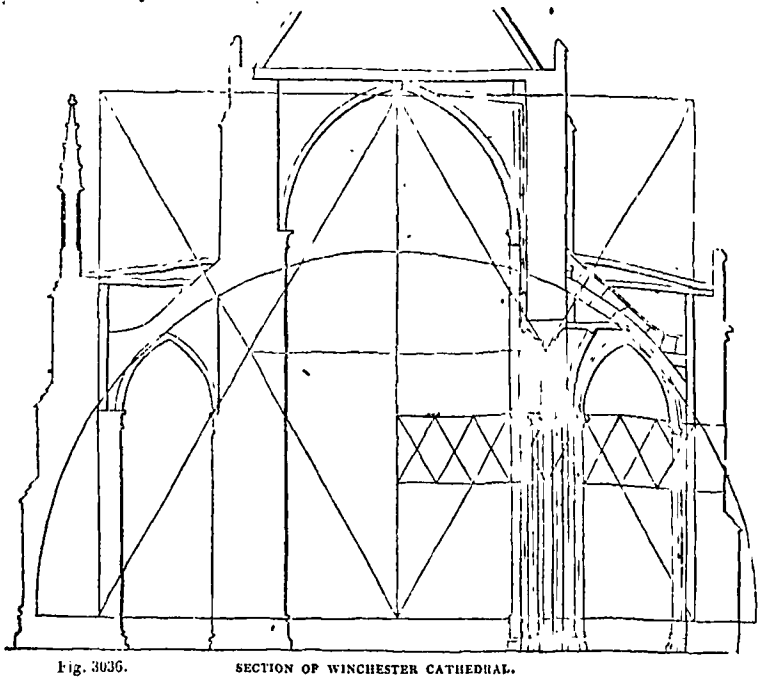


Fig. 3036. SECTION OF WINCHESTER CATHEDRAL.

from the face of the outer buttress to the centre of the section contains 36 small equilateral triangles, six of which cover the pier; consequently it occupies on the section one-sixth of that quantity; no further calculation is requisite to find the proportion it bears to the whole: in like manner the other parts of the section may be compared. Such was the use of equilateral triangles in the middle ages for ascertaining quantity.

The two equilateral triangles which occupy the nave and a portion of the piers are comprised within the figure called a Vesica Piscis; if the horizontal line drawn at half the height, uniting the base of the upper and lower triangles, be taken as a radius, and its extremities as centres, it will be evident that parts of circles may be struck, comprising the two triangles within them. Euclid has shown that a perpendicular may be raised or let fall from a given line by a similar method, the space between the segments being called afterwards a nimbus; and there can be no doubt that from time immemorial all builders have used it: the bee adopts for its honied cell a figure composed of six equilateral triangles, and this is proved to be the most economical method of construction; the sides of each hexagon are all common to two cells, and no space is lost by their junction. The nearer the boundary line of a figure approaches the circle, the more it will contain in proportion to it,

but circles could not be placed above and under each other, or side by side, without interstices occurring, and the equilateral triangle, or a figure compounded of it, is the only form that will admit of it being so arranged.

The interior and exterior division of the choir at Winchester exhibits two styles; the latter is a fine example of the decorated elegance to which architecture had arrived at the commencement of the sixteenth century.

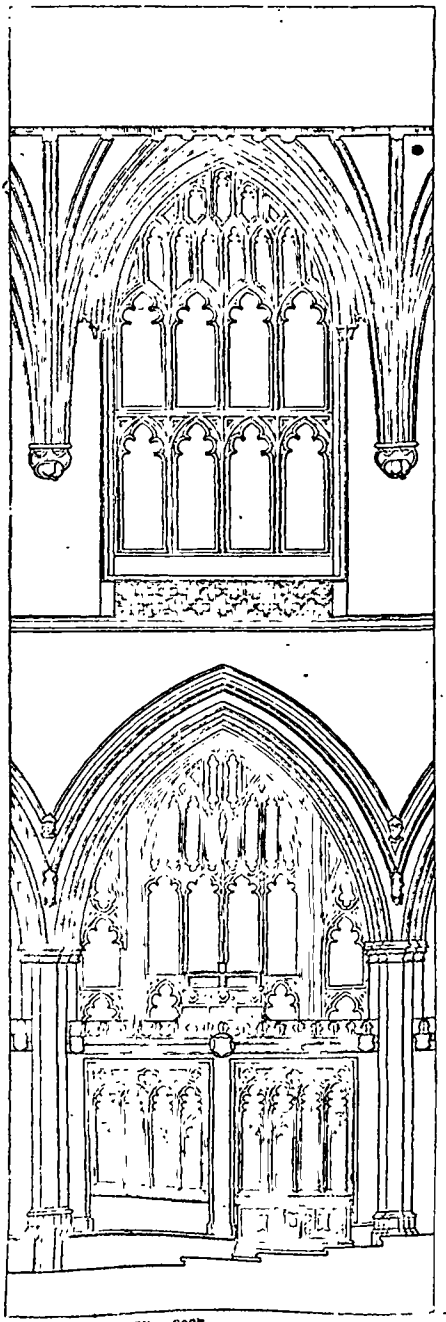


Fig. 3037.

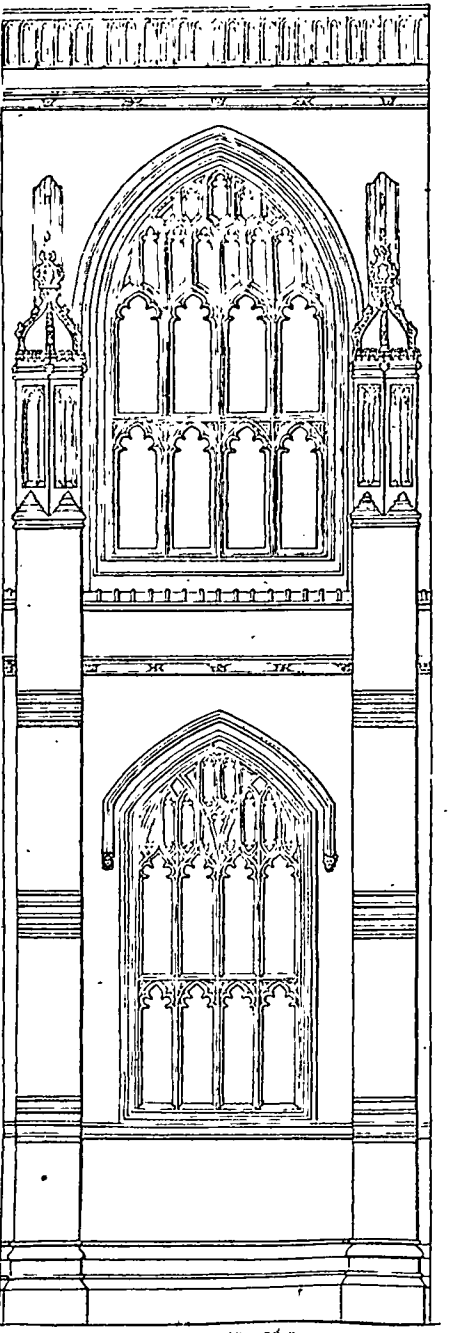


Fig. 3038.

WINCHESTER CATHEDRAL: CHOIR.

King's College Chapel, Cambridge, has no side aisles, but in lieu of them are small chapels between the buttresses, which are not interrupted in their depth, their whole strength being requisite to maintain in equilibrio the highly wrought stone vault; this they have hitherto perfectly done, to the admiration of all who have studied its principles of construction. The chapel is divided in its length into twelve equal divisions or severies, each of which is formed of four quadrants of a concave parabolic conoid standing on their apex, and is bounded by a main rib or arch of masonry which has its abutments secured by the weighty buttresses added to the outer walls. The width of each severy from centre to centre is 24 feet, the thickness of the buttresses being 3 feet 7 inches, and the length of the chapel between them 20 feet 6 inches; their depth is 13 feet 6 inches in the clear.

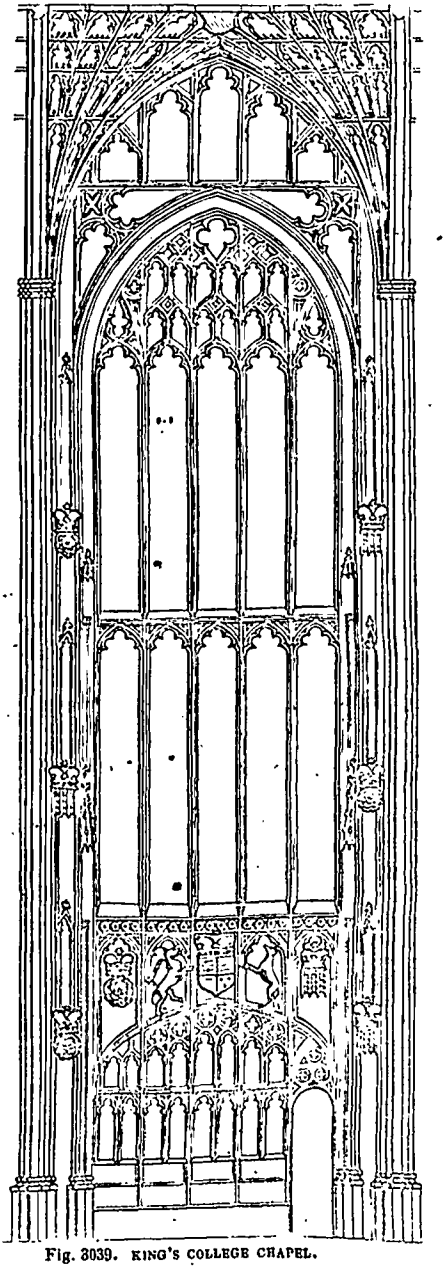


Fig. 3039. KING'S COLLEGE CHAPEL.

The transverse section shows more particularly the proportion of mass and void, which are here equal: the total extent or width from the face of one buttress to that of the other is 84 feet, and the clear width 42 feet; the height from the pavement to the top of the stone vault is 80 feet 1 inch, though this varies from the pavement being out of the level; the thickness of the walls at top is 5 feet 7½ inches; in it is a gallery 2 feet 1½ inch wide, and 7 feet high, communicating entirely around the building.

The height of the cluster column, whose capital receives the points of the inverted cones, is 59 feet 3 inches, so that the arch, which is struck from four centres, does not rise more than 18 feet 6 inches, and the intersections take place at one quarter of the span when the height is 15 feet 6 inches: this arch or stone rib is 2 feet in depth and 18 inches in breadth, formed of twelve vous-soirs on each side, the joints radiating to the centres respectively; it abuts at its extremities against the ponderous buttresses, and remains steadfast and immovable, dividing, as before stated, the vault into several severies.

The plan of the main piers shows that there has been no after-thought grafted upon the original design, which, in all probability, was commenced soon after the year 1446, as we find that a stone quarry at Haselwode, and another at Huddlestone, in Yorkshire, were granted, for the works to be carried on here. The stone roof does not appear to have been commenced till about 1512, the indenture concerning it bearing date the fourth year of King Henry VIII.; in this document Thomas Larke is called the "surveyor," John Wastell the "master mason," and Henry Semerk one of the "wardens," the two latter agreeing to set up a sufficient vawte, according to a plat signed; the stone to be from the Weldon quarries: the contracting parties were also to provide "lyme, scaffoldyng, cinctores, moles, ordinances," and "every other thyng required for the same vawting: the timbers

of two severies of the "great scaffolding" were given them for the removal of the whole; and they were to have the uses of all "gynnes, whels, cables, hobynatts, saws, &c.;" they were to pay for the stone, and to have 100*l.* for each severy, or 1200*l.* for the whole, money being advanced for wages as the works proceeded: the "chare roff," as the vault is called, was to be sufficiently buttressed, and the whole performed in a perfect manner.

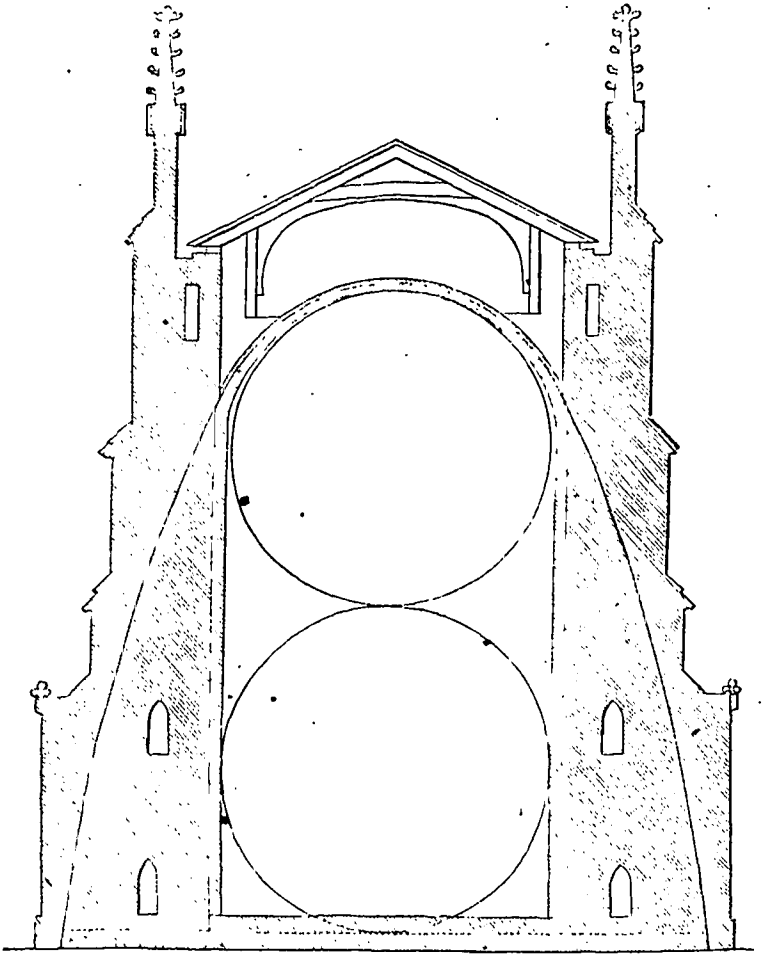


Fig. 3040. SECTION OF KING'S COLLEGE CHAPEL.

The extreme width, measured from the face of one buttress to that of the other, is 84 feet, and from north to south, from the centre of one pier to that of the other, 24 feet; thus the area comprised in a severy, or space between two lines drawn through the centres of the buttresses on the plan, is 2016 feet, exactly double the area of one of the severies of St. George's Chapel, Windsor: the extreme width is the same, but the difference arises from the divisions in the one being double that of the other, as measured from east to west.

	Feet.
The area of the nave, 42 × 24 - - - - -	1008
of the chapel on one side - - - -	336
ditto on the other - - - -	336
of the walls on one side - - - -	168
ditto on the other - - - -	168

Hence we have for the areas of the space or void on the plan 1680 feet, and for the walls and pier 336 feet, or one-sixth of the whole 2016 feet, similar proportions to those which we

shall afterwards find in St. George's Chapel, Windsor. In King's College the nave comprises half the entire area of a severy, and the remaining half is divided into three, one of which is given to each of the chapels, and the other divided between the points of support: in this beautiful building, with its majestically contrived roof of stone, the lightest construction is adopted. The catenarian curve exhibits the direction of the thrust of the vault, which falls within the base.

The stone roof we are now examining differs somewhat from that of Henry VII.'s chapel at Westminster; the area of the points of support is only one-half of those in the latter elegant example; in no instance have we so much effect produced by the mason's art, with so small a quantity of material: it is evident that the gradual changes made in the architecture of the mediæval period led at last to the greatest perfection, beyond which it seems impossible for us to advance.

In selecting a style of any one period, it may be fairly asked whether the principles found in the latter, or the economy adopted in the constructions of the 15th century, might not be applied to it, and the same effect produced,—the section of the chapter-house at Wells, for instance, lightened of half its material: undoubtedly it might, for the lofty pointed arch, not having the thrust which the latter, struck from four centres, had, would exert less thrust, and be in favour of such a change.

But at the present day, when copies are rigidly made of the finest examples of each style, it would seem a bold innovation to suggest such an adoption; still it might be introduced, and probably would have been, had the freemasons continued an operative fraternity, and been required to build in the Lancet or other style, which superseded it. The same decorations and form of arch may be used in the later styles as in the earlier, as far as construction is concerned, and we have evidence of sufficient strength in the example before us; the principles are the same in each, though they may differ in form; there would be no more difficulty in transforming one style to that of another, than was experienced by William of Wykeham, when he changed the Saxon nave of Winchester to the Perpendicular.

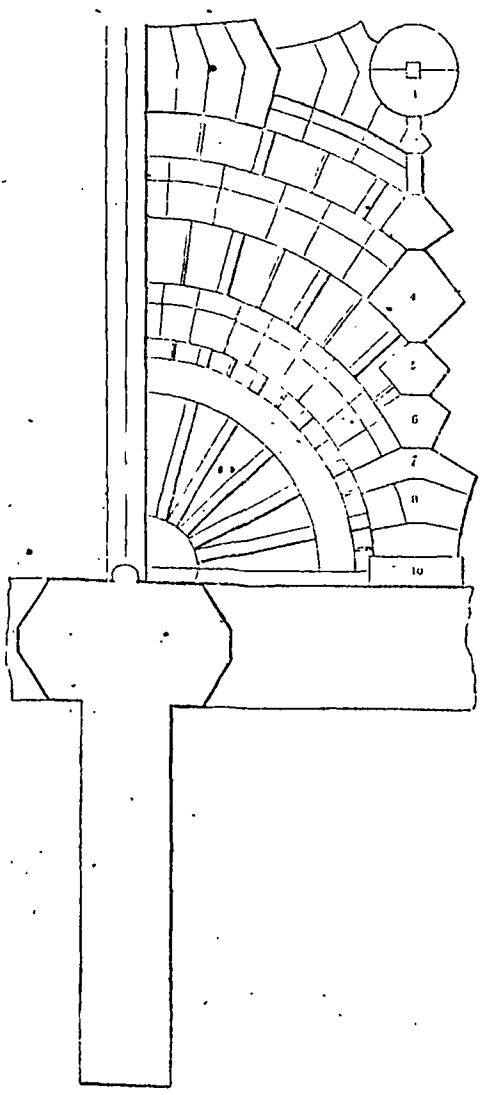


Fig. 3011. VAULTING OF KING'S COLLEGE CHAPEL.

On the section shown at fig. 3040. a line is drawn exhibiting the catenarian curve, for the purpose of showing that the abutment piers are set out in correspondence with its principles; it is not contended that a knowledge of this curve guided the freemasons in proportioning their piers, or that their flying buttresses were always placed within it; but it is singular that in those structures where their true position seems to have been decided, the catenarian passes through them.

Bath Abbey section (fig. 3051.) is an example which exhibits this most perfectly; and by a comparison of its section with that at Wells, (fig. 3004.) it will be perceived that the struts are differently placed, and that the earlier example is defective: fig. 3030. represents Roslyn

Chapel, in which there is evidently some improvement; but at the time of its construction perfect knowledge on this subject had not been attained. In a catenarian chain formed of links of equal length, every side is a tangent to the curve, and the direction of each link is at right angles to it, acting in a direction perpendicular to the line it forms in the catenaria; and hence its useful application to the science of construction. It is quite clear that wherever the curve passes through the section of a building, stability is obtained; and where it does not, it is doubtful: certainly the best application of flying buttresses is that which can be tested by this principle.

The main arches of the roof abut against the outer buttresses, and spring from a cluster of mouldings set round a circular pier; the situation of the small columns and hollows which decorate it being determined by the crossing of equilateral triangles. The ribs of each severy abut in the centre upon a circle 8 feet 6 inches in diameter, formed of two stones, and indicated by No. 1.: in the middle is a mortise-hole 9 inches square; No. 2. is in width 17 inches in the widest part; No. 3. is 2 feet 2 inches; No. 4., 3 feet 8 inches; No. 5., the same; No. 6., 3 feet 3 inches; No. 7. 4 feet 3 inches; No. 8., the same; No. 9., 3 feet 2 inches, and No. 10., which abuts against the outer wall, 4 feet.

By a reference to the plan on fig. 3044., it will be understood how the several rings of voussoirs which compose the quarter of the parabolic conoid abut and are locked one into the other: the construction of this vault is somewhat similar to that adopted by Soufflet at the Church of St. Geneviève at Paris, although his manner of applying it materially differs.

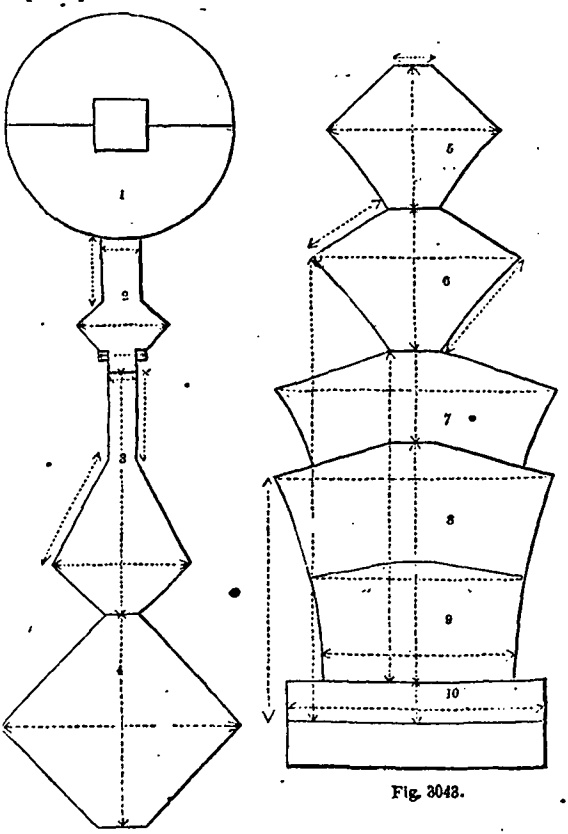


Fig. 3042. KING'S COLLEGE CHAPEL: RIBS OF VAULT.

Fig. 3043.

The buttress in the present example has an area of 56 feet, equal to that of the piers, to which it is attached; or the two piers and buttresses together have an area of 224 feet: it is curious to find that of the 336 feet before given to the points of support, one-sixth should be applied to the piers, one-sixth to the buttresses, and the other portion to the walls between; for 55 ft. 6 in. × 6 = 336 feet—the area of the points of support taken on both sides; so equally are the parts even distributed.

When the Normans first used flying buttresses, as at the Cathedral at Chartres, the Abbaye aux Hommes at Caen, and several other buildings, they abutted them against the ordinary outside wall; but it was soon discovered that a greater resistance was necessary to oppose the thrust, and prevent the abutments from yielding. Salisbury Cathedral was probably one of the earliest where flying buttresses were used; and the opinion of Sir Christopher Wren is worthy of quoting upon this subject, as it applies more particularly to the first constructed, and not so immediately to those erected in the fourteenth or fifteenth centuries. "Almost all the cathedrals of the Gothic form are weak and defective in the poise of the vault of the aisles; as for the vaults of the nave, they are on both sides equally supported and propped up from spreading by the bowes or flying buttresses, which rise from the outward walls of the aisles: but for the vaults of the aisles, they are indeed supported on the outside by the buttresses; but inwardly, they have no other stay but the pillars themselves, which, as they are usually proportioned, if they stood alone, without the weight above, could not resist the spreading of the aisles one minute: true, indeed, the great load above of the walls and vaulting of the nave should seem to confine the pillars

in their perpendicular station, that there should be no need of butment inwards; but experience hath shown the contrary, and there is scarce any Gothic cathedral, that I have

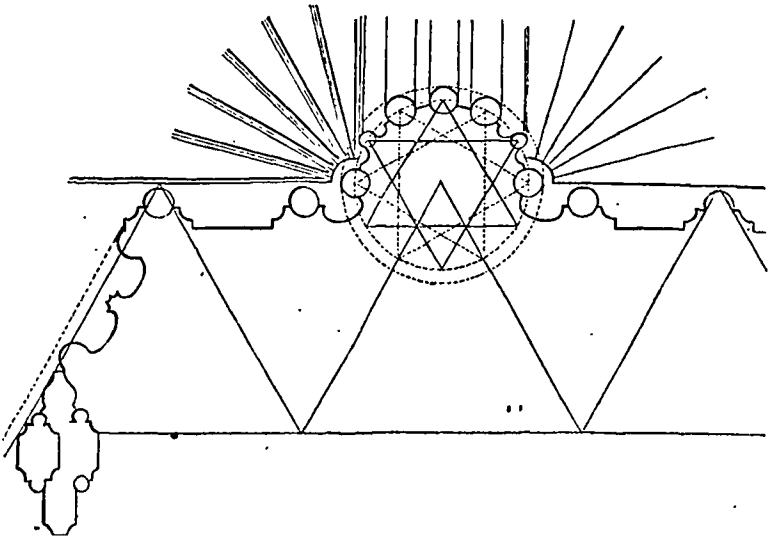


Fig. 3044. KING'S COLLEGE CHAPEL: PIERS.

seen at home or abroad, wherein I have not observed the pillars to yield and bend inwards from the weight of the vault of the aisle; but this defect is the most conspicuous upon the angular pillars of the cross, for there not only the vault wants butment, but also the

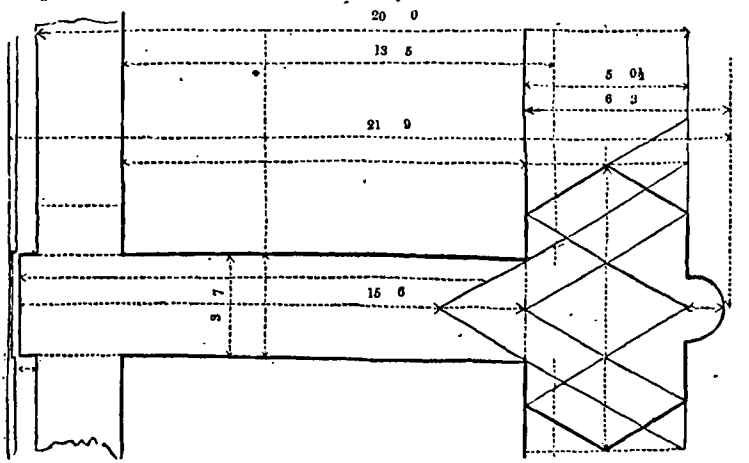


Fig. 3045. KING'S COLLEGE CHAPEL: BUTTRESSES, ETC.

angular arches that rest upon that pillar, and therefore both conspire to thrust it inwards towards the centre of the cross."

At King's College chapel, flying buttresses are dispensed with, and happily the knowledge of construction had arrived at such perfection, when its astonishing vault was projected, that we have no evidence whatever of its yielding in any part.

It may seem extraordinary that the Pointed style made so little progress in Italy, the Byzantine being always preferred: the architects of that country were probably unwilling to relinquish a mode of construction so economical, half only of the material employed in the lightest, and a quarter in the earliest of the Gothic style, being required for the basilica: for example, where 100 rods of stonework would be used in the latter, 200 would be necessary for the style practised at King's College, St. George's Chapel, and Bath Abbey Church, and 400 for that of the Chapter-house at Wells; this result would lead to the conclusion, that no style is so well adapted for the wants of the present day as the Byzantine.

St. George's Chapel, Windsor. — If we suppose a line on the plan to pass through the centre of the buttresses and piers, and one severy of the nave to be defined, we shall have a width of 12 feet, and a length of 84 feet, the area of which is 1008 feet: after this we shall find the area of the walls and piers comprised within this severy to be 168 feet, or one-sixth of the whole; such are the proportions of mass and void found in this chapel. The clear width of the side aisles between the columns is 11 feet 9 inches; that of the nave 34 feet 10 inches, and between the outer walls 69 feet 2 inches: the height of the top of the vaulting of the nave is 54 feet 2 inches. The height up to the springing line of the great vault over the nave being equal to half the entire width, it is evident that two squares must comprise within them the entire building beneath this line; upon setting them out we find the nave and its pillars occupy one, whilst the other is given to the side aisles, external walls, and buttresses.

The Rev. John Milner, in his admirable treatise on the Ecclesiastical Architecture of England, which has been the text-book for all modern writers, states that "its rise, progress, and decline, occupy little more than four centuries in the chronology of the world: as its characteristic perfection consisted in the due elevation of the arch, so its decline commenced by an undue depression of it. This took place in the latter part of the 15th century, and is to be seen, amongst other instances, in parts of St. George's Chapel, Windsor, commenced by Edward IV. in 1482; in King's College Chapel, Cambridge, and in the Chapel of Henry VII. at Westminster. It is undoubtedly true that the architects of these splendid and justly admired erections, Bishop Cloose, Sir Reginald de Bray, &c. displayed more art and more professional science than their predecessors had done; but they did this at the expense of the characteristic excellence of the style itself which they built in."

"In St. George's Chapel we have the work covered with tracery and carvings of the most exquisite design and execution, but which fatigue the eye, and cloy the mind by their redundancy:" but we have also a building constructed with one-half the materials that would have been employed had the style practised in the chapter-house of Wells been adopted. The admirers of the Pointed style have not sought for the true principles which mark its several changes; they have not examined into its constructive arrangements; had they done so, they would have perceived that, as the skill of the freemasons advanced, and their workmanship improved, they economised material, constructed more solidly, and produced a richer and more harmonious effect, without sacrificing any of the principles which governed their practice; the improvements they made were as great as those noticed when the

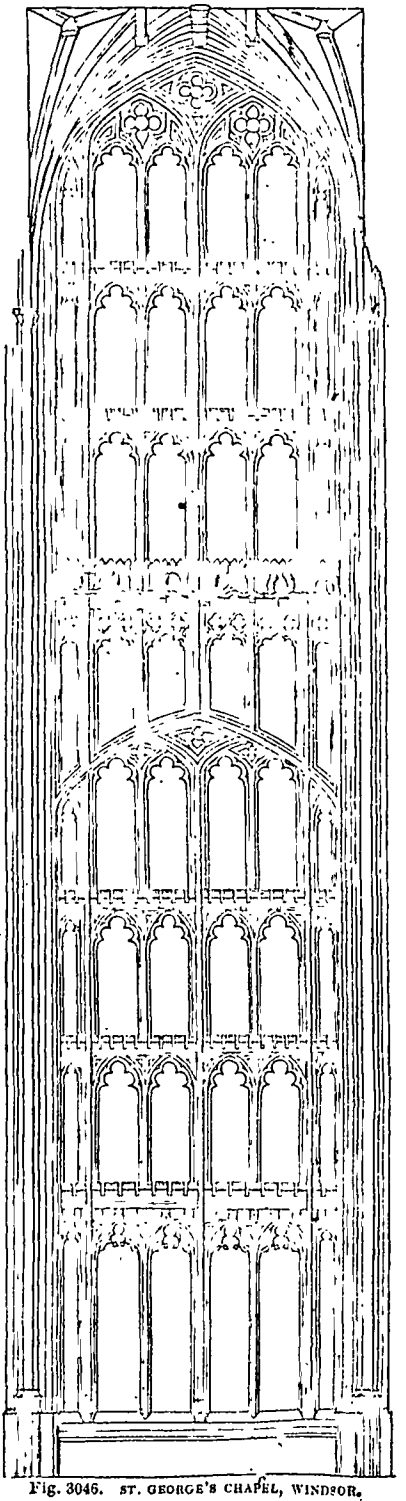


Fig. 3046. ST. GEORGE'S CHAPEL, WINDSOR.

Doric proportions were changed to the Ionic. In the Doric we had two-thirds mass, one-third void; in the Ionic half mass, half void; at Wells Chapter-house one-third mass, two-thirds void; in St. George's Chapel, one-sixth mass and five-sixths void.

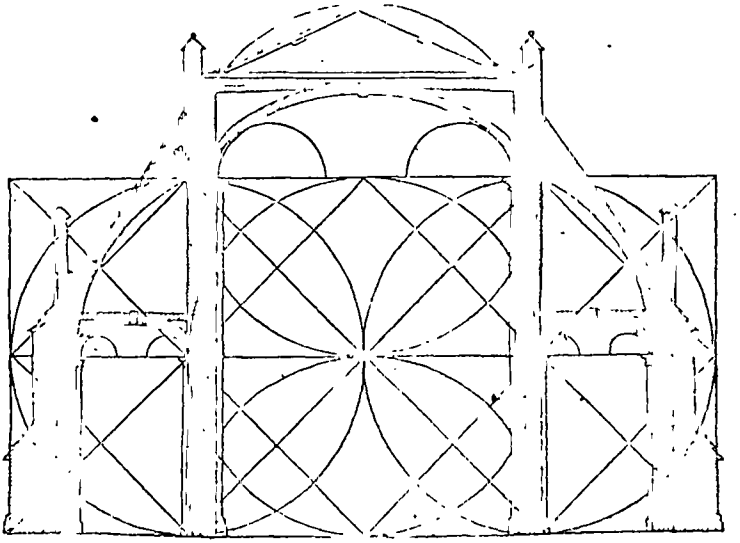


Fig. 3047. ST. GEORGE'S CHAPEL, WINDSOR.

The plan of the pillars is that of a double square, or parallelogram, the diagonals of which latter figure become the sides of equilateral triangles that serve for the setting out

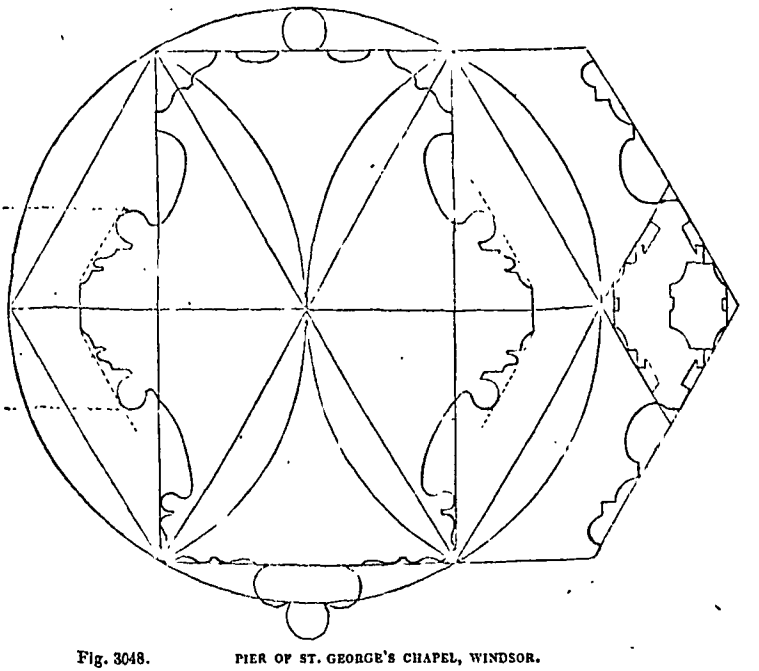


Fig. 3048. PIER OF ST. GEORGE'S CHAPEL, WINDSOR.

the splays, upon which the several mouldings are cut: from east to west these piers are 3 feet 1 inch, from north to south 3 feet 6 inches, not comprising in this last dimension the three

small columns on the fall towards the nave, or the single column on that towards the side aisles, the first of which projects 6½ inches, and the latter 4 inches.

The mouldings around the windows and their mullions are shown at the side of the pier in their proper position.

Division of the Nave of St. George's Chapel. — The mouldings set around the plan of the pier are continued up to the vaulting of the roof, without any other interruption except where they are mitred round the arches.

Bath Abbey Church is 89 feet 5 inches in width from cut to cut measured across the nave, and the clear width of the nave is 29 feet 10 inches, or one-third of the whole, and each of the side aisles is a trifle more than the half of the width of the nave, being 25 feet 8 inches; the walls and piers added together are not quite equal to a third, as they amount only to 14 feet 2 inches on each side, or together to 28 feet 4 inches, the difference being given to increase the side aisles.

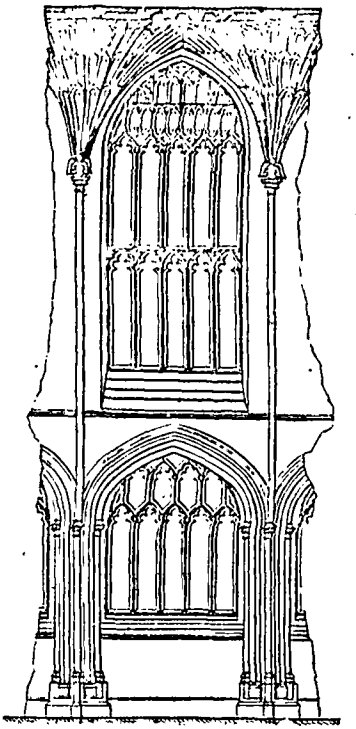


Fig. 3049. BATH ABBEY CHURCH.

The section of this beautiful building presents to us all the improvements made in vaulting, and the right proportions as well as directions to be given to the flying buttresses: in the first application of those supports, as at Salisbury, they are evidently misapplied, but in the example before us we find that the constructors had arrived at a knowledge of the principles of the catenarian curve, which is traceable through the solid masses of the section: it was by slow degrees that the freemasons arrived at a knowledge of the peculiar properties of this figure; had it been known at the first commencement of the introduction of flying buttresses, we should have had a better application of them; in several instances we find them adopted where no advantage, or very little, could be derived from them.

Division in Bath Abbey Church differs from all other examples of this period, by the height given to the clerestory and the omission of the triforium: the judicious and excellent arrangement of the flying buttresses permits of the greater display of glass, which in the sixteenth century had arrived at its most gorgeous state, rich in every colour, and beautiful from the drawing of the patterns, and figures with which it was covered.

Bishop King commenced this building about the year 1500, on an entirely new site, near the old church: from the centre of one pier to that of the other is 20 feet 1 inch; the thickness of the outer buttresses 3 feet, and their projection 4 feet; one severy of building contains 1650 feet, and the area of the points of support is 275 feet, or one-sixth. The pillars are square, though set diagonally, their width from north to south and from east to west being 5 feet, and the opening of the arches between them 15 feet 1 inch; half their plan and base is shown at fig. 3052.: the height from the pavement to the top of the capitals, where the sculptured angel is placed, is 56 feet 3 inches, and to the top of the vaulting 73 feet 6 inches, within 7 feet as much as the clear width between the outer walls.

Fig. 3053. shows the plan of the stone vaulting, which is perfectly geometrical in its setting out; the cloisters at Gloucester, the aisle at the east end of Peterborough cathedral, and St. George's Chapel, Windsor, have vaults of a similar kind.

The thickness of the stone which comprises the vaults of fan tracery varies according to its position, but in no instance is it considerable, or more than absolutely necessary to resist crushing. The spire of Salisbury, 180 feet in height, of an octangular form, measures from east to west internally 33 feet 2 inches, and from north to south 6 inches more; the thickness of the spire at bottom is only 2 feet, or the area of its base is half that of the void, the void containing two parts, and the solid around it one; this spire diminishes in thickness for the first 20 feet, after which it is 9 inches in thickness throughout; at about 30 feet from the summit is a hole, by which an exit from the interior may be made, and by means of the crockets and irons on the outside the top of the spire may be attained: in 1816 the writer examined the position of the vane, and the manner in which the capping stone was placed, and descended astonished at the perfection of the masonry, and the thinness of the stone with which it was constructed.

Fig. 3050.

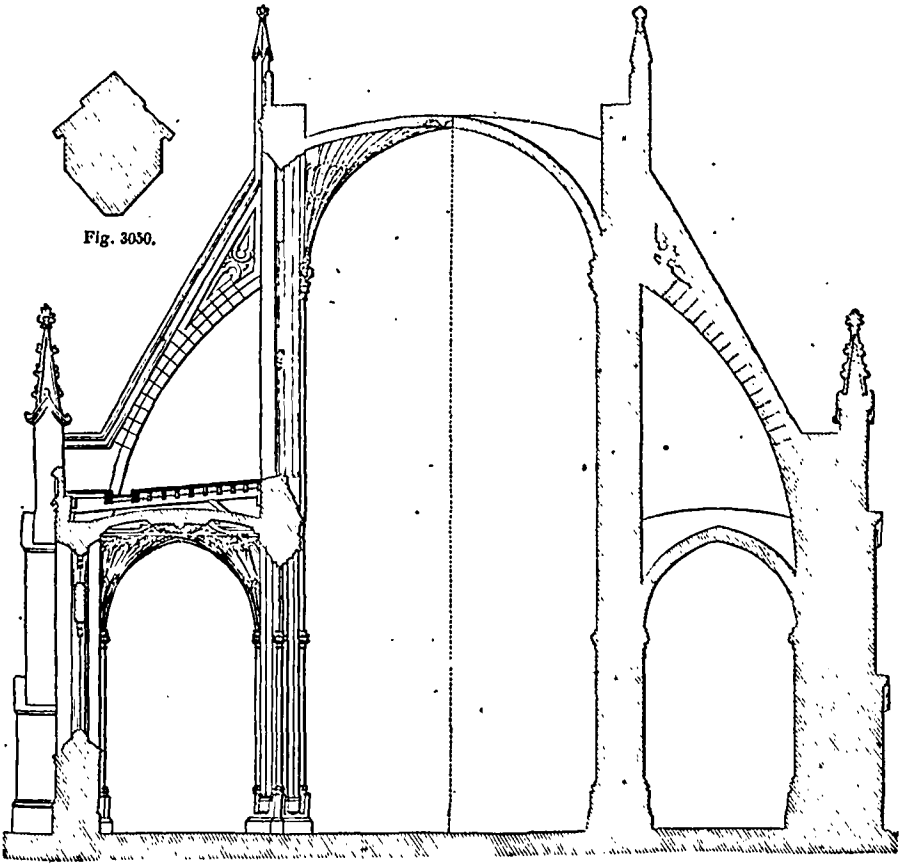


Fig. 3051. SECTION OF BATH ABBEY CHURCH.

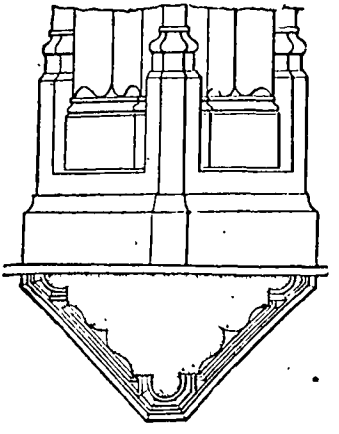


Fig. 3052. PIER.

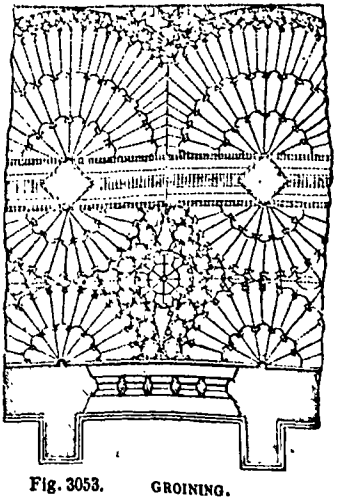


Fig. 3053. GROINING.

Caudebeck Sacristy, near Rouen, in Normandy, exhibits the manner of suspending a key-stone by locking it between the voussoirs of a strong semicircular arch. The length of this

pendent stone is 17 feet 6 inches, and its thickness at the top, where locked, is 30 inches: the voussoirs are 3 feet in depth; the small pointed arches or ribs that form the groining of the hexagonal vault spring from the side walls and the ornamental knob of the pendentive, and are perfectly independent. The abutments of the semicircular arch, which has a radius of 12 feet, are formed by solid walls continued for some length in the direction of its diameter. This sacristy is hexagonal; each side internally measures 12 feet, and the height from the pavement to the springing of the ribs is 18 feet.

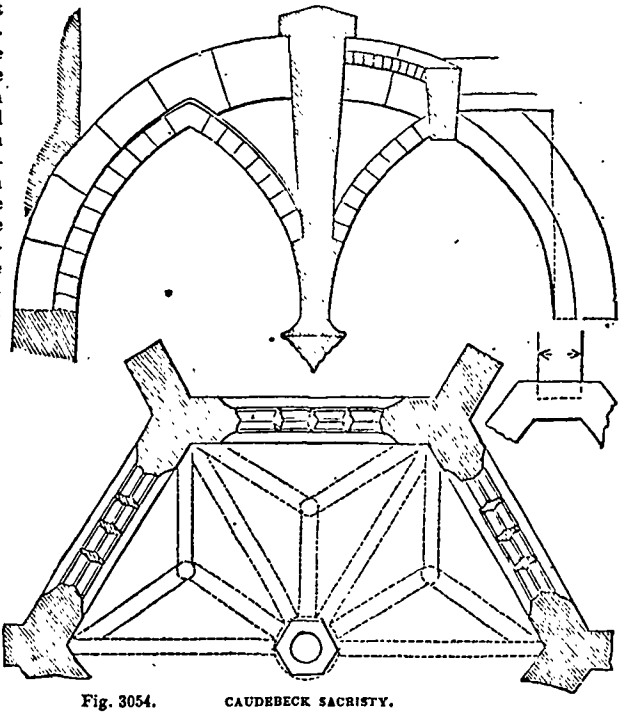


Fig. 3054. CAUDEBECK SACRISTY.

Henry the Seventh's Chapel, Westminster.—The first appearance of the pointed arch was probably a little before the termination of the twelfth century; the pillars and mouldings which then accompanied it were of Saxon origin: to its acute form was

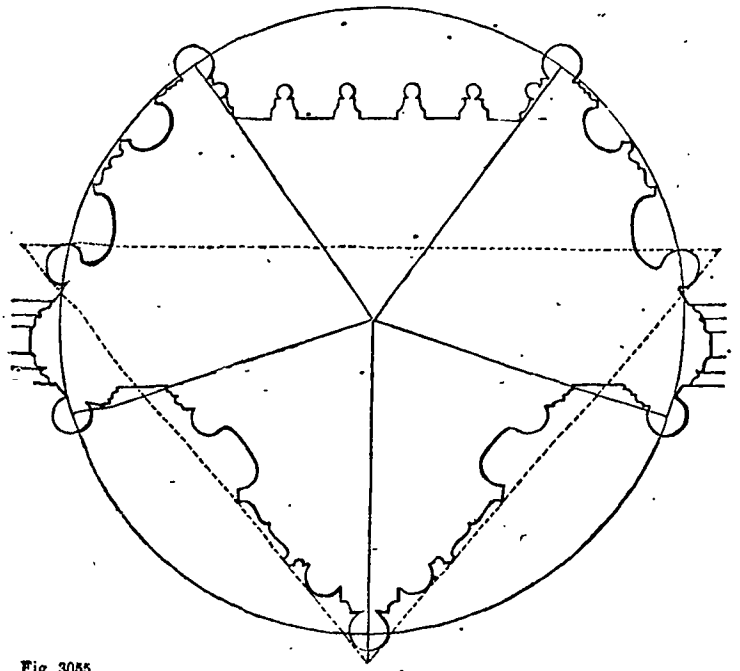


Fig. 3055. PIER OF HENRY VII.'S CHAPEL.

afterwards added the slender Purbeck columns and simple groining, producing that unadorned majesty which reigns throughout the cathedral of Salisbury. This style underwent several changes, and was succeeded at the latter end of the thirteenth century by another, in

which the arch was struck from more than two centres: the naves of York, Canterbury, and Winchester Cathedrals have been cited as among the best examples. But we have now to describe the principles of a style founded upon the others, and applied to all buildings in England from the middle of the fifteenth to the middle of the sixteenth century; it is not met with on the continent, the Italian or revived classic architecture having there been generally introduced and preferred.

The variety exhibited in groined vaults, progressing from simple ribs to those of an intricate and net-like arrangement, no doubt led the masons of the time to the construction of the cloisters at Gloucester, King's College, and Henry the Seventh's Chapel at Westminster, which works are the best evidences that can be adduced of the improvements made in professional science, and which could only result from a continued perseverance in the study of the subject: an examination of the several styles will prove that they must have been produced by the same school or fraternity, and that neither Sir Reginald Bray nor William of Wykeham could have become acquainted with the mysteries of the craft, unless they had been instructed by the freemasons; and that to them, and not to any individual, nor to the clergy as a body, ought we to attribute the construction of these scientific and highly decorated works.

The Division of Henry the Seventh's Chapel bears a strong resemblance in its general proportions to that of St. George's at Windsor, although it is rendered more ornamental by the multitude of figures enshrined in delicate tabernacle-work, which covers almost the entire walls. The mouldings of the main piers (fig. 3055.) that separate the middle from the side aisles are enclosed within a circle divided into a pentagon—a form the best adapted to receive the weight of the ribs, and the flying buttresses that were to resist their force.

The Rev. James Dallaway, whose discourses upon the architecture of England, created so many admirers of this interesting subject, observes, that "here the expiring Gothic seems to have been exhausted by every effort. The pendentive roofs, never before attempted on so large a scale, are prodigies of art." But it is not to the profusion of sculptured angels, statues, royal heraldic devices, &c., that we are desirous of drawing the attention, so much as to the extraordinary construction that prevails throughout this master-piece, in which we have the strongest evidence that theory and practice went hand in hand; that the knowledge of geometry had advanced to its highest pitch in the constructive arts, and that not only were the principles of the arch thoroughly understood, but considerable advance made in the application of the properties belonging to the cone.

The section of this beautiful chapel is 78 feet in width; the buttresses and outer walls together are 9 feet 9 inches, the side aisles 11 feet 3 inches; the piers from north to south 4 feet

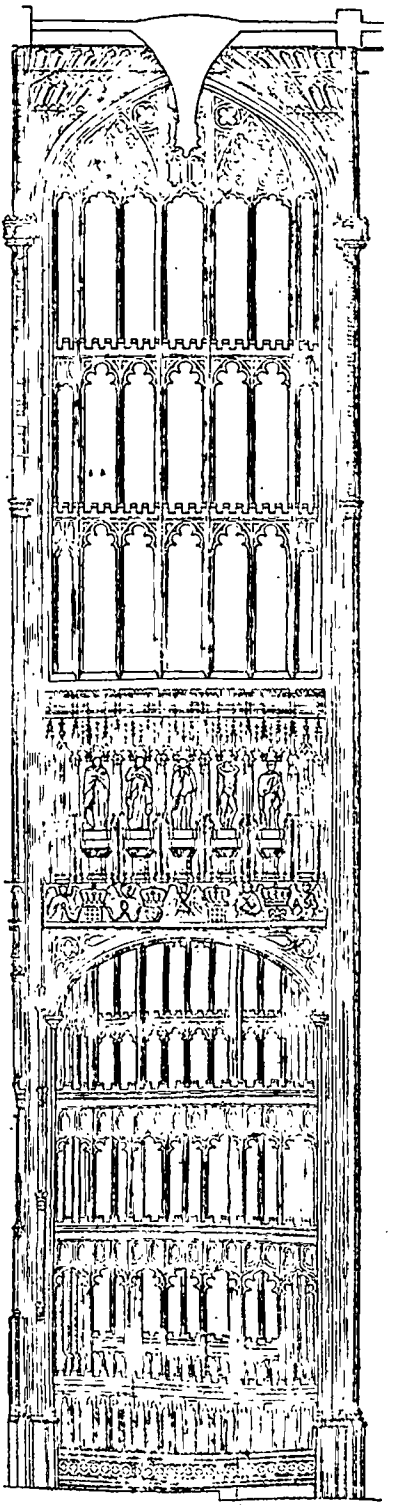


Fig. 3056. HENRY VII.'S CHAPEL.

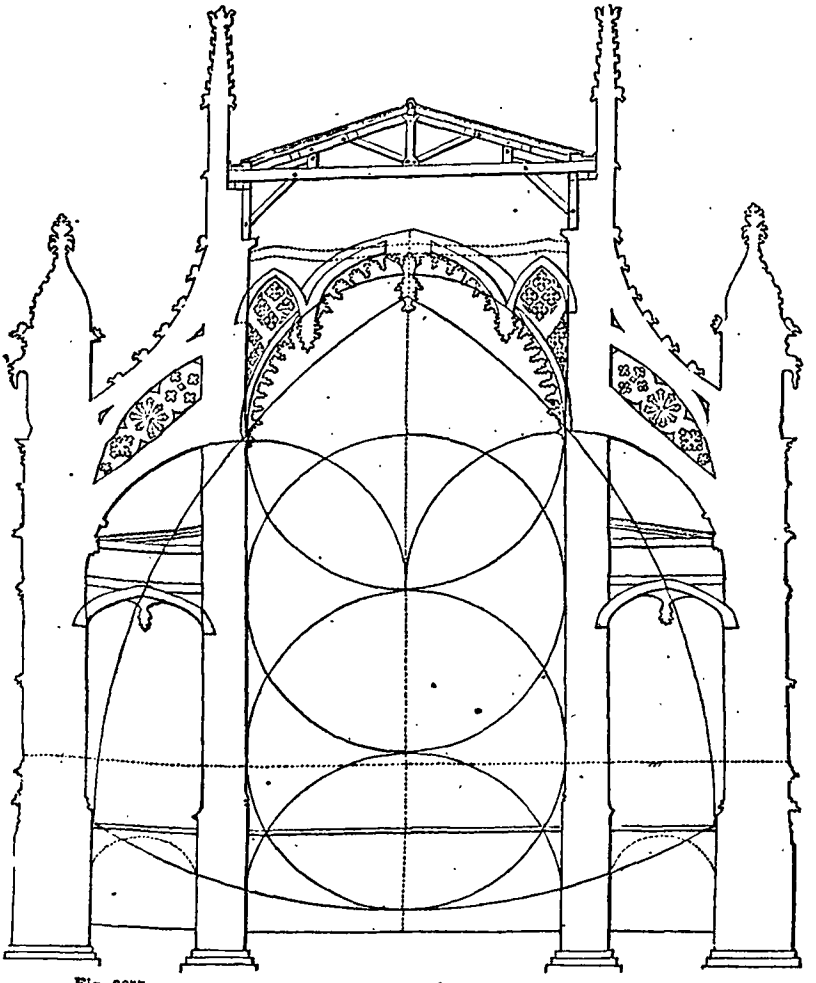


Fig. 3057. SECTION OF HENRY VII'S. CHAPEL.

6 inches, and the clear width of the nave 33 feet. The entire width, at the basement or level of the pavement of the crypt, is 79 feet: 26¼ feet, or ⅓, is devoted to points of support, and 52¾ feet, or ⅔, to the side aisles and nave; the area of a severy shows ⅓ applied to walls and piers, and ⅔ to the void, which proportions accord with the early rather than with the late examples; the great weight of the vaulting, which is 62 feet high from the pavement of the chapel, requiring additional strength, the proportions of St. George's Chapel at Windsor would not have been equal to the necessary resistance.

Our limits will not permit a more extended inquiry into the principles of proportion, the study of which is calculated to produce an important improvement in the noble art, for the practice of which the young architect must prepare himself by careful measurement, not only of the ruins of the Acropolis and of the Capitol, but of all that remains of mediæval architecture: he must be a pilgrim seeking after truth, not bowing before any favourite shrine, but returning with a devotion as enlarged as his subject. The stupendous works which antiquity has transmitted to us, it is hoped, may excite the attention of the general reader, nor will his interest be diminished by the contemplation of the astonishing development of modern industry. The writer cannot but feel the importance and variety of his subject, and, while he is conscious of his own imperfections, he must often accuse the deficiency of his materials: but the results of his labour, however inadequate to his own wishes, he finally delivers to the candour of the public.

INDEX.

	Page
Abattoirs in Paris	286
Absolute strength of timber	1303
Acacia, timber	1284
Acherusia Palus	140
Acres, the quantity of, in England and Wales	759
Acridina, city of	57
Acrita	621
Actus, single carriage road	149
Adrian, villa of	93
Agetor	75
Agonalis, circus of	119
Air-pumps	1217
Alabaster	704
Alban Lake	192
——, tunnels at	193
—— stone	97
Alber timber	101. 1284
Alberti, Leon Battista	212
Alburnus	65
Alexandria, city of	32
——, reservoirs of water	34
Allatri, city of	70
Aluminum	653
Alveum	131
Amiens, rose window	1615. 1617
Ammanati	163
Amphitheatres —	
Adria	108
Adrian	108
Ægeda	108
Agrigentum	108
Alba	108
Arezzo	108
Argos	108
Arles	109. 118
Autun	108
Beneventum	108
Besançon	108
Bordeaux	108
Bruieres	108
Cahers	108
Capua	108
Cassano	108
Castrensis	108
Catania	108
Amphitheatres —	
Constantium	108
Cuma	139
Die in Dauphine	108
Doue	108
Drenaul	108
Drevant	108
El Jemm	119
Fedena	108
Fesole	108
Florence	108
Frejus	108
Hispalis	108
Istria	108
Jerusalem	108
Lucca	108
Lyons	108
Melos	108
Metz	108
Minturno	108
Narbonne	108
Neri	108
Nice	108
Nismes	108
Orange	108
Otricoli	108
Pæstum	65. 108
Palermo	108
Parentium	108
Paris	108
Perigeaux	108
Placentia	108
Pola	108. 119
Pompeii	108
Pozzuoli	140
Puteoli	108
Saguntum	108
Saintes	108
Sardis	108
Smyrna	108
Syracuse	60. 108
Tarragona	108
Tergeste	108
Toulouse	108
Udena	108
Valonges	108
Verona	48. 108
Vespasian	108
Vienne	108
Anchor of ships, weighing of	998
Anemometers	1216
Angles	738. 859. 868
——, to be given to lock-gates	1549
Antarctic Ocean	635
Antimony	655
Ants, turret-building	725
Apodyterium	128. 131
Apollonius, the geometer	782
Appian Way	148, 149
Apulia	183
Aqua, Alsietina	175, 176
—— Aniene nuovo	176
—— —— vetus	175
—— Appia	97. 170. 175
—— Claudia	174, 175
—— Julia	175
—— Tepula	169
—— Virgo	170. 175
Aqueductibus Urbis Romæ	169
Aqueducts of iron	597
—— of timber	549
Aqueducts —	
Buc	286
Carpentras	266
Carthage	184
Civita Castellana	158
Constantinople	185
Croton	299
Evora	184
Frejus	182
Jouy	183
Lisbon	185
Lyons	179
Marcia	175
Maintenon	285
Marly	286
Metz	182
Montpellier	264
Nicomedia	185
Nismes	177
Pont-y-Cysyllte	567
Segovia	184
Spoleto	158
Tarentum	147
Volsci	179
Udena	184
Aradus, city of	5
Arc de Cloitre	1450

Page
Arch, antiquity of 22. 32. 70. 73. 194
—— of Coningsburgh Castle - - 410
——, construction of 1521
——, development of 1435
——, equilibrium of 1427. 1505
——, flat - - 1430
——, of bridges 1486
—— formed of flexible timber - 419
——, groined - - 1442
——, hexagonal - 1455
——, pointed, at Arpeno - - 70
——, semi - - 1428
——, skew - 1436. 1457
——, triumphal - 145
——, their proportions - 1596
——, three arcs of a circle - - 1487
——, wedges which form - - 152
——, weights applied to - - - 421
Arch, triumphal, of Augustus at Pola 1598
——, of Augustus at Aosta - - 1597
——, of Augustus at Susa - - 1599
——, of Poliphele - 1595
——, of Septimus Severus - - 1599
——, of Sergius at Pola - - 1598
——, of Titus at Rome - - 1598
——, of Trajan at Beneventum - 1600
——, proportions given to - 1596
Architecture - - 1579
——, Cyclopean - 67
——, Gothic - - 1602
——, Greek - - 79
——, hydraulic - 205
——, Roman - - 1590
——, Saxon - - 1601
Archimedes - - - 58
——, screw of - 1567
Arctic Ocean - - 635
Area of land, how computed - - 848
Areas of a sphere. - 876
Argand fountain lamps - - - 244
Argives - - - 68
Argos, city of - 72. 75
Argosies, or ships - 144
Aristotle, death of - 47
Arithmetical proportion - - - 766
Arnold's escapement 982
Arsenals - - - 138. 238
Arsenic - - - 656
Arsinoe, city of - 51
Artemisia, Queen - 196
Artesian wells - 291, 292
Articulata in Geology 621
Artificers' work, value of—
Beton - - 909
Binding-pieces, labour - - 902
Brickwork - 908
Carpenters' work 897
Cofferdams - 900.
Dredging - 897
Earth, removal of 896
——, levelling - 897
Entretoises - 901
Fascines - - 898
Fences - - 898
Foundations, carpentry of - 902
Groined work - 896
Iron work - 910
Joists, labour on 904
Piling - - 899
Planking - - 899
Planks - - 904
Platforms - 902
Stonework - 908
Timber, labour on - - 903
Timber, carriage of - - 904
Timber, raising 903
Turf, laying down - - 897
Artificial globes - 756
—— islands - - 136
—— stone - - 724
Ash, wood of - 100. 1284
Asphaltum - - 728
Astrolabe - - 825
——, to measure distances - - 827
——, to measure heights - - 825
——, to measure depths - - 828
——, to measure widths - - 827
Athens, city of - 41
Atlantic Ocean - 635
Atmosphere, density of - - - 207
——, as a moving power - - 1216
Atomic weight - 643
Atwood, experiments on falling bodies - 921
Augusta Prætoria - 89
Augustus, house of - 93
Aulis, mole of - 47
Aurelian, walls of - 86
Autun, city of - 92
Avernus, lake of 139, 140
Axis, horizontal - 957
—— of rotation - 939
Axles - - - 1271
Azimuth circle - 809

Bacciali, Giovanni - - 206
Backwater, its effects 322
Bag and spoon - 1058
Balance-bridge of iron 326
Ballast machine - 1058
Balneum - 121. 131
Baltic Sea - - 635
Banks, slope of - 1142
—— to resist inundations - - - 324
Baptistery at Pisa, section of - - 1617
Barium - - - 651
Barnabeta - - 206
Barometer - 207. 845
—— to measure heights - - 845
Bars, Bootham - 404
——, Micklegate - 406
——, Monk - - 405
——, Walmgate - 407
Barton, Spanish - 931
Bascule for pumping 1195
Basilica of Constantine 98—100
—— at Fano - - 104
—— of Paulus Emilius - - 100
Basin of Hull Docks 326
Bath Abbey Church 1632
Baths, manner of heating - - 125
—— of Agrippa - 120
——, Badenweiller - 130
—— of Caracalla - 93
—— at Chester - 128
—— of Constantine - 93
—— of Diocletian - 93
——, Greek - - 122
—— of Hippias - 122
—— of Julius Cæsar 120
—— of Livia - - 94
—— of Nismes - 131
—— of Paulus Emilius - - 120
——, Roman - - 120
—— of Scipio - 125
—— of Stura - - 130
—— of Titus - - 94
——, Wroxeter - 128
Battering engines at Rhodes - - 47
Beach, sea - - 642
Beams, strength of - 1258
——, fishing - - 1304
——, motion of steam-engine - - 994
Bearings of carriages 1023
Beauvais Cathedral - 1614
Beech, wood of 101. 1284
Beetle, three-hand - 1071

Page
Belfast - - - 398
Belidor's machine - 1204
Belisarius, miles of - 203
Bellows for forging - 1041
Bends of rivers, to measure - - 837
Beneventum, city of 148
Bernareggi, Isidoro - 206
Bevelled gear - 942
Birch, wood of - 1284
Birds, in geology - 521
Bismuth - - 655
Bitumen - - 728
Blast furnaces - - 682
Block machinery - 1042
Blouett's baths - 130
Blowers of iron forges 1041
Blue - - - 104
Boats for transport - 1023
—— for bridges . 66, 67
Bodies, action of - 923
——, regular - - 890
Bogs, drainage of - 1558
Boilers, steam - 1251. 1271
——, cylindrical - 1252
——, materials for making . - 1252
——, rectangular - 1252
——, waggon head - 1252
Boiler plates, punching - - 1036
——, apparatus for feeding - 1255
Bolting machines - 1049
Bond in brickwork - 710
——, plates and timbers - - 1306
Boning lines - - 805
Boom chains - - 334
Booming - - - 805
Boring instruments - 694 1060. 1062
Boring, machines for 1031
Boron - - - 649
Boundaries of lands 759
Bourse at Paris - 290
Bouse ore - - 663
Box, wood of - 101. 1284
——, shovel - - 1057
Brakes of carriages - 1019
Brass - - - 610
Breakwater, Plymouth - - - 366
Bresica, red - - 100
Bricks - - 93, 94. 709
—— used in the pyramids - - - 28
——, kilns - - 709
——, fire-bricks - 710
——, floating - - 710
——, retorts - - 710
——, machine for making - 711

Bridges —
Aberaven - - 426
Albias - - - 265
Page
Bridges —
Alexandrié - - 163
Alford - - 468
Allier - 161. 251
Allness - - 468
Ambrussum - 159
Angelo, St. 154. 157
Assise, near Tours - - 1398
Avignon - - 250
Avon, cast-iron 497. 506
Bachiglione - 157
Baiæ - - 139
Ballater - - 468
Bamberg - - 1381
Bassano - - 1367
Bellecour - - 274
Berghette - - 157
Berne - - 1376
Bettwys - - 426
Bewdley - - 463
Bishops Auckland - - 414
Blackfriars - 427
Blois - - 251
Boisseron - - 158
Bonar - - 498
Bord - - - 265
Bordeaux - - 280
Bosphorus - 66
Boucherie - 215
Brighton - - 518
Bristol - - 430
Brives - - 266
Broughton - 520
Brunoi - - 273
Brussells - - 1370
Buildwas - 461. 494
Cæsar's - - 1349
Caligula - - 95
Capo Dorso - 158
Carbonne - - 266
Carlisle - - 473
Carraja - - 163
Cartland Crags - 1405
Castellane - 253
Cephissus - - 66
Ceret - - 253
Cestius - - 156
Chalons - 251. 270
Chamas, St. - 159
Change Au - 251
Charmes - - 256
Chateau Thierry 272
Chatellereau 251. 254
Chavannes - 272
Chazey - - 1376
Chenonceaux - 250
Cher, near Tours 1398
Chester - - 461
Choisy - - 1380
Civita Castellana 158
Clair, St., on the Rhone - 1365
Claix - - - 253
Page
Bridges —
Clement's, St. - 1378
Clyde at Glasgow 1363
Coldstream 433. 1405
Colebrook Dale 493
Collingen - - 1375
Compeigne - 256
Conan - 468
Concorde - - 251
Conway - - 517
Corvo, near Aquino - - 163
Craig Ellachie - 503
Cravant - 256. 1399
Cremera - - 158
Croyland - - 416
Cyrus - - 67
Danube, near Ulm - - 1364
Darius, over Ister 66
Delaware - - 1382
Dieppe - - 1364
Diez, St. - - 274
Dole - - 264
Drone - - 266
Dryburgh - - 508
Dunkeld - - 468
Durance - - 250
Edinburgh - - 468
Edme, St. - 1400
Elbe - - 214
Esprit, St. - 252
Exchange - 255
Fabricius - 154. 156
Fairness - - 468
Feldkirch - - 1379
Felice - - 163
Ferrato - - 156
Fochabers - 468
Fouchard - 251. 269
Freysingen 1356. 1380
Frouart - - 274
Galashiel - - 507
Gignac - - 273
Glasbury - - 426
Glasgow - - 463
Gloucester - 462
Goldsmiths - 162
Gooda - - 1368
Grenelle - - 1377
Guillatière - 2502
Hammersmith - 509
Hamoaze - - 1393
Havre - - 1387
Helmsdale - 468
Helvoetsluys - 1388
Herault - - 273
Hexham - - 433
Homps - - 272
Houfleur - - 1388
Horbourg - 269
Hotel Dieu 251. 255
Hutcheson - 470
Hyde Park - 460
Ingersheim - 266
Isere - - 253

Bridges — Page
Janiculum 154. 156
Jardin du Roi - 283
Juvisi - - 255
Kelso - 434. 508
Kosen - - 215
La Crau, near Arles - 254. 284
Lary - - 506
Lavaur - - 270
Laythorpe - 415
Lempde - - 272
Libourne - - 281
Limmat - - 1374
Llanwast - - 417
Loire - 251. 1371
Loiret - - 1369
London - 412. 441
Londonderry - 426
Louis XVI. 273. 1515
Louvre - - 281
Lovat - - - 468
Lyons - - 1366
Macon - - 251
Maestricht - 255
Maligny - - 274
Mammea - - 157
Manchester - 504
Mantes - 264. 1400
Marachia - 165
Marche Palu - 254
Marie - 251. 255
Marlow - - 520
Maxence, St. 251. 270. 1551.
Mazeres - - 272
Mediolanum - 161
Mellingen - - 1377
Menai - 509. 513
Meuse - - 1378
Michel, St. 251. 255
Micklewood - 520
Military School - 279
Milvius - - 153
Mireppis - - 274
Monnou - - 413
Montelimart - 274
Montignac - 266
Montilun - - 274
Montrose - - 518
Mossen - - 215
Moulins 251. 263. 1404. 1514. 1517.
Mulatière - - 1368
Musselburgh - 435
Naville - - 270
Necker 1365. 1369. 1378
Neuf Pont 251. 254
Neuilly 251. 268. 1402. 1493. 1515. 1516.
Nemours 274. 1403
Neucettringen - 1380
Neuville - - 269
Newhaven - 518
Newton Stewart 435
Nogent - - 265
Nomentano - 155
Norfolk - - 520
Notre Dame, Cahors - - 1370
———, Paris 251. 254
Nottingham - 471
Nurembourg - 215
Orleans 254. 1403. 1514
Ouse - - - 472
Palatine, or Ponte Rotto - - 154
Palladios - - 1366
Pavia - - 162
Peas - - 468
Peebles - - 507
Perth - - 430
Pesmes - 251. 266
Pilantio - - 158
Pisa - - 163
Pontilieu - - 266
Port de Pile - 257
Portsmouth - 1383
Portumna - - 506
Potarch - - 468
Prague - - 214
Quatro Capi - 156
Queen's, Ireland 473
Ratisbon - - 215
Ravinnes - - 274
Rhone - - 1378
Rialto - - - 163
Richmond - - 1383
Rieucross - - 274
Rimini - - 157
Roanne - - 274
Rochester - - 414
Rosoi - - 273
Rotto Ponte - 154
Rouen - - 276
Rumilly - - 272
Saintes - - 161
Salara - - 155
Salarius - - 153
Saone - - 1376
Sarah - - 475
Saumur 251. 258. 1490.
Saut du Rhone 250
Savines - - 1373
Schaffhausen - 1373
Schonnenberg - 1369
Schuylkill - 1385
Seine - - 1377
Semur - - 270
Serriere - - 278
Seurre - - 1380
Sevres - - 276
Simplon - - 274
Sisteron - - 253
Sisto Ponte - 156
Sommieres - 159
Sorges - - 265
Southwark 498
Spoleto - - 158
Staines - - 458
Stoneleigh - - 436
Sublicius - 154. 1350
Sunderland - 495
Susquehanna - 1383
Taaf - - 426
Tees - - 1386
Terni - - 158
Têtes - 256. 1372
Teviott - - 468
Tewkesbury - 504
Toledo - - 1516
Tongueland - 463
Toul - - 256
Toulouse - 251. 254
Tournelle - 251. 255
Tournou - - 253
Tournous - - 1377
Tours - 251. 263
Trajan's - 158. 1350
Trilport - - 257
Trinity - - 163
Triumphalis - 154
Tuilleries - - 255
Utrecht - 1368. 1386
Vaison - - 161
Vecchio, Ponte - 163
Verona - - 165
Vicenza - 157. 163
Vieille Brioude 253
Villeneuve - 253
Vizille - - 272
Vrach - - 1365
Waterloo - - 436
Wellesley - - 473
Wellington - 436
Westminster 422. 429. 1404
Witham - - 497
Wurtzburg - 215
Wychbree - 426
Xerxes, over Hellespont - - 66
York, over the Ouse - - 415
Zurich - - 1375
Zwettau - - 215

Bridges built by Gephyræans - 66
——, abutments of, thickness - 1496
——, abutments at Orleans - 1521
——, arches, their form - 1357. 1484
——, arches, experiments upon - 1498
——, arches, construction of - 1521
——, balance - - 329
——, boats of - 661. 1393
——, breadth of - 1485
——, centres of - 1402
——, drawbridges - 1389
——, floating - - 1393

Page

Bridges, first built over the Tiber - - 85
——, form of piers - 1507
——, foot - - - 1362
——, foundations of - 1518
——, Nicias at Delos 52
——, piers of - - 1506
——, quay-walls of - 1516
——, rolling - - 1391
——, of ropes - - 1392
——, starlings of - 1514
——, suspension 518. 520
——, principles of - 1350
——, swing - - - 1386
——, timber - - 1346
——, turning iron - 335
——, waterway of - 1478
Broadstairs - - 396
Bronze seats - - 129
Brothers of the Bridge - - - 250
Brundusium - - 148
Brunswick wharf - 1527
Bruschetti, Giuseppe 206
Buckets, brazen 203. 1206
Buffing apparatus - 1023
Building, strength of 104
——, within cities - 92
Bulk of bodies, to ascertain - - 1117
Burners, construction of - - - 1241
——, Argand - - 1241
Burning bodies - 196

Cables and capstans - 231
Cadmus - - - 81
Caissoons, to trace 238. 1431
——, for bridge building - - 259
——, used at Toulon 238
——, at Westminster 423
Calcareous gritstone - 628
Calcium - - - 652
Caligula, bridge of - 139
Callais, or mountain road - - - 149
Cambrian system - 632
——, lower do- - 633
Camel for raising ships 1054
Caminus, or Chimney 131
Campbell's tomb in Egypt - - - 21
Cams in machinery - 980. 1566
Camus's pile-engine - 967
Canals - - 1551. 1560
Canals—
Aberdare - - 556
Aberdeenshire - 556
Abiato - - 187
Adige - - 188
Aire and Calder - 556
Albana, Val d' - 188
Albany - - 295

Canals— Page
Albinia - - 187
Alford - - 556
Ancholme - - 555
Andover - - 557
Arun - - 552
Ashby de la Zouche - - 557
Ashton-under-Lyne - - 557
Avon - - 557
Barnsley - - 557
Basingstoke - 557
Bassanallo - 188
Baybridge - 557
Beverley Beck - 557
Bianco di - - 188
Birmingham and Liverpool 557, 558
Blyth - - 560
Black river - 295
Bologna - - 187
Borrowstounness 560
Bradford - - 560
Brecknock - 560
Brenta novella - 188
Briare - - 249
Bride - - 561
Bridgewater - 560
—— and Taunton - - - 561
Britton - - 561
Brondo - - 188
Bure - - 561
Burgundy - 249
Bury - - - 561
Caistor - - 561
Cajuga & Seneca 295
Calder and Hebbel - - 561
Caledonian - 561
Carbonania Fossa 185
Carlisle - - 564
Champlain - 295
Charolais - - 245
Chemung - - 295
Chesterfield - 565
Chinango - - 295
Corbulonis Fossa 185
Coventry - - 565
Crinan - - 565
Cromford - - 566
Crooked Lane - 295
Dearne Deve - 565
Delaware - - 296
Derby - - 565
Dora Batea - 187
Dorset and Somerset - - 565
Droitwich - 565
Drusiana Fossa - 185
Dudley - - 565
Edinburgh and Glasgow - 565
Ellesmere and Chester - - 565

Canals— Page
Erewash - - 568
Erie - - 295
Exeter - - 568
Forth and Clyde 568
Foss Navigation 569
George, St. - 187
Geresee valley - 295
Glamorganshire 569
Glasgow and Paisley - - 569
Glenkenns - 569
Gloucester and Berkeley - 569
Grantham - 571
Gresley - - 571
Harecastle - 575
Hereford - - 571
Hartlepool - 571
Horncastle - 571
Huddersfield - 571
Hull and Leven 571
Ivelchester - 571
Junction, Grand- 570
Kennet - - 571
Kidmelly - - 571
Lancaster - - 571
Languedoc - 248
Leeds and Liverpool - - 571
Leghorn - - 188
Leicester - - 572
Leominster - 572
Leven - - 572
Liskeard and Loe 572
Lledi - - 561
Loing - - 249
London & Cambridge - - 572
Loughor - - 561
Louth - - 572
Macclesfield - 572
Maestra Fossa - 187
Malshum - - 249
Manchester and Bolton - - 572
Marduck - - 222
Mariana Fossa - 185
Market Weighton - - 572
Martenaro - 187
Martesana - - 186
Medicina - - 187
Monkland - - 572
Monmouthshire - 572
Montgomeryshire - - 572
Morris - - 296
Mosolino - - 187
Muzza - - 187
Narbonne - - 248
Naviglio della - 187
Neath - - 572
Newcastle - - 573
Newport Pagnell 573
Northampton - 572

	Page
Canals —	
Norwich and Lowestoft	573
Nottingham	573
Nulbrook	573
Ohio	296
Ollegio	187
Orleans	250
Oswego	295
Oxford	573
Padua	188
Peak Forest	573
Phillistina Fossa	185
Picardy	249
Piedmont	187
Pocklington	573
Ponfilio	188
Portsmouth and Arundel	573
Puzzola, Fossa di	187
Rangone Fossa	187
Regent's	575
Rochdale	573
Rye	573
Salisbury and Southampton	573
Sankey	573
Schuylkill	297
Secchio	187
Sheffield	573
Shrewsbury	573
Shropshire	573
Somersetshire	573
Staffordshire	574
Stainforth	574
Stourbridge	574
Stratford-upon-Avon	574
Swansea	574
Tavistock	574
Tesino	187
Tetney haven	575
Thames and Medway	574
—— and Severn	574
Trent and Mersey	575
Ulverstone	577
Union, Grand	571
Walsham	573
Warwick	577
Waveney	561
Weaver	577
Western, Grand	578
Wey and Arun	577
Wilts and Berks	577
Wilts, North	573
Wisbeach	578
Witham	573
Worcestershire	578
Wyrley and Essington	578
Yare	561
Canals and river locks	1533
Cane, hydraulic	1165
Canterbury cathedral	1620
Canusium	148
Caps of windmills	1219
Capstan, varieties of	997
Caracalla, circus of	119
Caravelli, Don Vito	147
Carbon	649
Carboniferous system	630
Carbury, Count de	999
Carpentry	1305
Carriages for boats	297
—— for railways	1020
—— for ships	347
—— of timber, how valued	904
—— for weights	1017
Carts in Italy	1020
—— used by Perronet	1018
—— for railways	1019
Cartwright's steam-engine	981
Carybdis, Pool of	64
Carystos, or Castel Rosso	100
Casks for floating bodies	230. 352. 385.
Castelli, Benedetto	207
Castles	139. 409. 411
Catacombs	60
Catch piers	345. 401
Catch-water drains	540.
Catenarian arches	419
Caudebeck sacristy	1636
Cauking	1306
Causeways	10. 541
Cedar, wood of	1285
Celestial arc, measurement of	748
Cella Solearis	123
Cellular pumps	1197
Celsus on rain water	165
Cement	721
——, kilns for burning	717. 721
——, mills for grinding	1049
—— for aqueducts	176. 181
Centre of cutting on canals	1533
Centres of timber	1395
——, Perronet's	1399
—— at Chester Bridge	461
—— at Gloucester Bridge	462
Cephalopoda	621
Cessart, Louis Alexandre de	227
Cetras	75
Chains of iron	1574
——, endless	955
—— for lifting stone	1024
—— for measuring land	846
——, pumps	1176
——, suspension	514
Chain and offset staff	846
——, Gunter's	846
Chalcis, mole of	47
Chapels on bridges	415
Chalk	626
——, green	109
——, marl	710
Chapel of Henry VII., Westminster	1634
Chapelets	1057. 1195
—— worked by water	1197
Chesnut timber	101. 1285
Chimneys, their origin	131
——, area for	1257
Chlorine	646
Chœreas, the engineer	75
Chorabates	166
Chords and arcs	820
Chromium	655
Churches, roofs of	1316
Cippolino marble	704
Circei	75
Circeum	88
Circles	741
——, area	874
——, circumference of	746. 874
——, diameter of,	874
——, proportions of	746
——, to reduce to a square	880
——, to reduce to an oval	881
——, to reduce several to one	888
——, to triple and double,	884
Circumferenter	862
Circular staircases	1468
Circular alternate motion changed to continuous	960
Circus	119
Cirrhopoda	621
Cissiæ, machines	1015
Cisterns for water	168. 544
Clay, Kimmeridge	628
——, London	624
——, Oxford	628
——, Wealden	627
——, for brick-making	709
Cleavage	635
Clepsydra	35
Clock-making, history of	974
Clutch or gland	950
——, bayonet	950
——, friction	950
Coaking engine	1043
Coal	630
—— fields	694
—— fields in Scotland	694
—— mines, how lighted	696
Cobalt	656
Cobb composed of rock	385
——, walls	727

Page
Cocking or cogging - 1304
Cocks, stop and metal 167
——, fourway - - 1260
——, sluice - - 1214
Cofferdams 269. 430. 446. 465. 468. 1518, 1519.
Cogs - - - 1566
Cohesive strength - 1293
Colechurch, Peter - 412
Coliseum - 93. 96
Colossus - - - 48
—— of Claudius - 138
Colours used by the Romans - - 103
Column of Antoninus 198
—— of Trajan - 198
Comitium - - 85
Compressibility - 917
Conches or locks - 186
Conchifera - - - 621
Concrete 25. 309. 724
Conduit pipes of clay 94. 172. 1139.
——, of metal - - 1226
——, for heating - 127
Cones - - - 758
——, to construct - 781
——, to find their superficies - 877
——, their solidity - 877
Conic sections - - 782
Conisterium, apartment - - - 122
Conoid, parabolic - 890
Contectis Piscinis - 169
Continuous rectilinear motion changed 954, 955
Contour lines on maps 802
Contract for London Bridge - - 455
Convex mirrors - 244
Copper - - - 670
Copying plans - - 870
Coral rag - - 628
Corlina - - - 99
Cornbrach limestone 628
Coryceum, apartment 122
Copper - - 51. 670
——, adit of mine - 675
——, alloys of - 671
——, crushing-mills for - - 676
——, oxides of - 670
——, riddling of - 677
——, sampling of - 678
——, sulphates of - 670
Corneil wood - - 101
Corvus or raven - 1006
Cos, Island of - - 54
Cosa, walls at - - 77
Cotton spinning - 976
Couplet on centres - 1408
Couplings - - 949
——, friction - - 950
Crab for raising weights - - 1001
Cradle for hoisting - 239
Cramping of stone - 379
Cramps, dowel and dovetail - - 1441
Cranes 1004. 1006. 1011
——, movable - - 1008
——, Perronet's - 1009
Crank - 1267, 1268
Crapone, Adam - 245
Crayon, Port - 868, 869
Cretaceous system - 626
Cross staff for measuring - - - 870
——, applied to angles 871
——, polygons - 873
——, rhomboids - 872
Ctenoidans - - 621
Ctesibius's pump - 204
Ctesiphon's method of raising weights 75. 201
Current, to find the velocity of - 636. 1139
Cutting knife for weeds - - - 191
Cyclops - - - 67
Cylinders 751. 781. 877. 955. 1275.
——, strength of metal 1258
Cypress, wood of, 108. 1285

Dædalus - - 80
Daily labour of men 1087
Dams, double - - 128
Danaide - - 959
Darius's Bridge over Hellespont - - 67
Degrees - - 748. 811
Demetrius, Poliorcetes 44
Denudation - - 623
Derrick cranes 1012, 1013
Desarque's pump - 1194
Devonport column - 1012
Dilatability - - 915
Dimchurch wall - 1558
Dinocrates - - 32
Divisibility - - 916
Delorme, Philibert - 1377
Delos, Isle of - - 69
Diaclos, or drawing plan - - - 44
Diades - - - 75
Diagonal lines - 736
Diallage, or serpentine 635
Diameters of circles - 874
Diatonous - - 1423
Diognetus - - 46
Dioptera - - 166
Diverticulum road - 149
Diving bells 1050, 1051
Docks at Antwerp - 214
——, Commercial - 310
——, Catherine's, St. 308
——, Chatham - 318
——, Cumberland - 363
——, Deptford - 314
—— Goole - - - 324
Docks, Hull - 325. 327
——, India, East - 312
——, India, West - 313
——, London - - 310
——, Ramsgate - 396
——, Sheerness - 318
——, how cleansed - 329
Dock-gates at Montrose - - 1553
—— —— at Woolwich - - 1554
Dodecaedron - 755. 779. 889
Dolabella, arch of - 97
Dolamite - - 702
Domenico's invention of locks - - 187
Domes - - - 1345
——, Assumption at Paris - - 1346
——, Invalides at Paris - - 1348
——, St. Mark at Venice - 1361
——, Salutation Church - 1347
——, spherical - 1459
——, Val de Grace - 1345
Domitian, villa of - 93
Dorians - - - 158
Doric temples - - 1580
Doron - - - 708
Dovetailing stone - 379
Downs or dunes - 642
Dragging - - 1520
—— for mud - - 1057
Drainage - 188. 1562
——, Belgium provinces - - 214
——, Fens - - 541
——, Hontsdam - 214
——, Nene outfall - 539
——, Pontine Marshes 188
——, Purmer Lake - 213
——, Romney Marshes 532
——, of towns - 543
——, Witham Marshes 537
Drain pipes - - 468
Draining and embanking - - - 1557
Drains in the amphitheatres - 112, 113
Drawing circles and ovals - - 773
—— parabolas - 773
—— polygons - 773
—— piles - - 1078
Drawbridges - - 1302
Dredging machines 329. 1057
——, bucket machines 347. 1058
——, value of work - 897
Drilling machines - 1030
——, hand and foot machines - 1031

	Page
Drivers to railway carriages	1278
Drummond's light	1230
Dykes, their construction	213. 1528
——, of Holland	213
Dynamometers 1064.	1254
——, Regnier's	1066
——, various, applied to machines	1068
Ear of Dionysius	60
Earthen pipes for water	166
Eau Branch cut	539
Ebony, wood of	101
Eckart's power capstan	1008
Edifices of Rome, materials used in construction	92
Edwards, William	426
Egeria, fountain of	94
Egnatiam	148
Elasticity	915
Eleusis	43
Elder, wood of	1285
Ellipse	74
Elm, wood of 100.	1285
Embanking and excavating	1567
—— and draining	1558
Emissarium	194
Emplecton	121
Engineering, history of, in America	293
——, Egypt	7
——, England	306
——, France	215
——, Germany	213
——, Greece	40
——, Holland	213
——, Phœnician	1
——, Roman States	83
Engines, steam	955
——, for boring	1033
——, fire	1196
——, high pressure	1255
——, locomotive	1271
——, raising water	202
——, steam-boat	583
England and Wales, area of	759
Eocene in geology	624
Ephebium, apartment	122
Epicycloid	940
Epures or drawings	781
Equation clock	982
Equilateral triangles	768
Equilibrium 934, 938.	1505
Escapements, recoil	983
——, ascending	984
——, Breguet's	974
Etruria	78
——, roads, &c.	83
Euripus, wooden bridge at	47
Evangelus	751
Excavations	1520
——, for piers of bridges	432
——, value of work	896
Exchange at Antwerp	214
Extension	915
Eyes, boring in metal	1036
Fall of water-wheels	1146
—— given to water	178
Faraday's lamps	361
Fascines for jetties 898.	231 1522.
Faults in mines	623
Felspar, analysis of	705
Fenders of oak	327
Fengite, marble of	99
Fens	541
Ferrari	206
Ferries over rivers	412
Field book for surveying	847
Figures, regular	866
——, equiangular	744
——, equilateral	744
——, irregular	877
——, isoperimetrical	745
——, multilateral	887
——, plane, to reduce	878
——, quadrilateral, to divide	886
——, rectilinear	884
——, triangles, to reduce to	879
——, unequal, to divide	888
Filters for cleansing water	1211
——, Mauras's system	553
Fir, wood of, varieties	1286
Fire basket for light-houses	332
Fishes in geology	621
Flashes for canals	568
Flats in canals	618
Flint glass	731
Floatation of bodies	1156
Floating 207.	229
——, equilibrium of	1154
Flora, circus of	119
Flood-gates, to raise	1106
Floors	1310
——, double-framed	1312
——, naked	1311
——, Roman	1426
——, single joists	1311
Fluids, pressure of	1133
Fluorine	647
Foccaci, Francesco	206
Foculare	129
Focus or hearth	131
Fontana, Carlo	1015
Force, measure of	916
Force, developed by the mover	1091
——, equilibrium of	917
——, mechanical labour	917
——, parallelogram of	919
Forcier for supply of water	544
Foreshores, how preserved	323
Forging of iron	34
Formæ, town of	34
Fortifications of the Greeks 74,	75
Forum	105
——, Appii	152
Fossombroni Vittorio	206
Foundations 225.	238
—— of bridges,	1518
—— of sea locks	225
—— of sluices	218
—— of London Bridge	447
Fountain of Hero	1156
Fowey Consols mine	674
Frames for building	180
Framing in carpentry	1310
—— partitions	1310
Freemasons, measuring by	750
Fresnel, Augustus	244
Friction	951
Frigidarium, apartment	121
Frisio, Paolo	206
Frontinus, Sextus Julius	169
Fucinus, lake of 140.	195
Fuel, consumption of	1281
Fullers'-earth beds	629
Furnaces, construction of 127.	709
Gabina, stone of	95
Gabions, construction of	1522
Gadsdon, Isaac	417
Galeasses	144
Galileo Galilei	207
Galleys built by the Rhodians	46
——, cut in the rock	72
Ganoidans	621
Gargouille	113
Gas lighting	1214
——, condenser	1235
——, gasometers for	1237
——, governors	1238
——, history of	1230
——, hydraulic mains	1235
——, mains	1239
——, purifiers	1236
——, retorts, &c.	1232
Garousse's lever	982
Gates turning on pivots	219

Page
Gates or entrances to cities - - - 69
—— of Augustus - 91
——, Circeium - 88
—— of the Lions at Mycenæ - 71
—— of canals - - 1102
Gauges for steam-engines - - 1254
——, water and tubular - - 1255
Gaunus, Mount - 148
Gear, bevelled - - 942
Geometry - 733. 835
George's, St., Chapel, Windsor - - 1630
Gephyræans - 66. 81
Giallo Antico marble - - - 703
Gin for lifting - 957. 959
Girders, strength of - 1312
Girgenti, town of - 63
Glass, its manufacture 731
——, machine for polishing - - 975
Globe - - - 701
Globular projection - 747
Gneiss system - - 633
——, its composition 654
Gnomonic, or central projection - - 746
Gold - - - 650
Goldsmith, arch of - 96
Gortyna, city of - 51
Gothic windows, their proportions - - 1608
Goubert's apparatus for raising ships - 1056
Governor or centrifugal power - - 1262
Gradients on railways 1567
Graham's dead beat - 983
Grandi, Guido - 206
Granite, Aberdeen - 634
——, graphite 383. 634
——, porphyritic 348. 634
Gravatt's level - - 797
Graving docks - - 294
Gravity, specific, of bodies, tables of - 1116
——, centre of - 921
——, earth's - - 1120
——, force of - - 920
——, metals - - 1117
——, woods - - 1119
—— of a circle - 921
—— of a cone - 921
—— of a paraboloid - 921
—— of a sphere - 921
—— of a segment - 921
—— of a sector - 921
—— of a trapezium - 921
—— of a triangle - 921
Greece - - - 40
Greenstones - - 634
Grilliage of timber - 221

Page
Groins, construction of - - - 1525
Groundwork, value of 896
Gudgeons - 948, 949
Guglielmini, Domenico - - - 207
Gunter's chain 846, 847
Gymnasium - - 120

Hadrian, circus of - 119
Halley's diving-bell - 1051
Hammers for forging - - - 1042
Harbours, *see* Ports.
Harmonical proportion - - - 766
Harry Grace de Dieu 314
Heat, radiation of - 1223
——, conduit pipes - 127
Hedgehog for rivers - 1059
Heights - - - 736
Helepolis - - 47
Heliogabalus, circus of 119
Hellespont, bridge over - - - 66
Henry VII.'s Chapel, Westminster - -
Heptagon - - 879
Hepteres - - - 137
Herodes Atticus - 50
Hexaedron - 755. 889
Hexagon - - - 887
Hexastyle temples - 1582
——, proportions - -
Hiero, palace of - 57
Hippodamus of Miletus - - - 46
——, several - - 148
Hippodrome of Constantine - - 95
Hoisting tackle - 1012
—— for the Menai Bridge - - 1027
Holly, wood of - 101. 1286
Hooke's universal joint - - - 950
Hooke, Dr., on the Catenarian - - 417
Horizontal line - 735
Hornbeam wood 101. 1286
Horse, power of - 1092
——, observations on 1093
——, daily work of - 1017
Hot-blast iron - 683
Hounslow Heath, base line on - - 853
Humber dock wall - 1526
—— basin piers - 1529
Hulls, Jonathan - 583
Hydraulics - - 34
Hydraulic traversing frames - - - 1281
—— docks - - 294
—— lime - - 721
Hydrogen - - 644
Hydrometry - - 207

Page
Hydrostatic balance - 207
Hydruntum - - 148
Hygrometric machine - - 990. 999
Hymettus, marble of 99
Hypersthene rock - 634
Hypocaustum - 121. 131

Icosaedron - 779. 889
Impact, or shock of water - - - 1197
Impenetrability - 915
Impression, centre of - 1115
Inclined plane - 296. 924
—— planes on canals. 1554
Indian Ocean - - 635
Inertia - - - - 916
Invertebrata in geology - - - 621
Iodine - - - 647
Ionic temples, their proportions - - 1587
Iron - - 620, 621. 678
——, its cohesion - 693
——, alloys of - - 681
——, assay of - - 679
——, corrugated - 693
——, cylinders - 307
——, cylindrical columns - - 691
——, Duleau's experiments on - 498
——, forging - - 685
——, furnaces - 682
——, galvanised - 694
—— hand used by Archimedes - . 58
——, moulding - 684
——, native - - 670
——, piles 313. 315. 549
——, planing - - 1048
——, plate bending - 1028
——, power of suspension - 507
——, proving machine - - 507
——, puddling - 685
——, revolving shafts - - 693
——, rolling, forging, &c. - 685
——, strength of 690. 693
——, sulphate of - 680
——, sulphuret of - 680
——, swivel bridges 328
——, teeth of wheels 946
——, tenacity of - 514
——, tension of - 693
——, valuation of work done in 910
——, weight, tables of 690
——, wrought - 685
Ischia - - - 139
——, limestone of - 95
Isodomum - - 1423
Isosceles triangles - 768

	Page
Iter, or bridle way	149
Jack for lifting weights	1001
Jacob's staff	832
——, for measuring heights, &c.	834, 835
Jessop, William	363
Jet of water, its height	1215
Jetties 217. 220. 226.	236. 1522
Joas Johnson	320
Joints in carpentry	1306
—— of arches	1428
——, socket	549
Joists, to proportion	1303
Journals	949
Juniper, wood of	101
Kaminus or chimney	131
Key, grooving	1037
Kilns for cement	721
King's College Chapel	1625
Knolles, Sir Robert	614
Labelye, Charles	422
Labour, mechanical	918
——, measure of value of	918
Laburnum wood	1286
Laconicum	121. 131
Ladders in mines	675
Lagunes	211
Lamp black	103. 728
——, apparatus for making	730
Land reclaimed from the sea	320
Lapping in carpentry	1307
Larch, wood of	101. 1286
Larnica, gulf of	51
Lateran, baptistery of	100
Lathe for turning	1029
——, without an axle	995
Latitude	757
Latomiæ, or quarries	60
Latrina	128
Laurel, wood of	101
Laurentinum of Pliny	122
Lavacrum	126
Lazaretto	209
—— Ancona	105
—— Genoa	209
—— Leghorn	210
—— Varignano	210
Lead mines	659. 661
—— casting	667
—— hushing	662
—— milled	667
—— *pipes*, forming of	100. 166. 667, 668
——, red	103
Lead, reducing	667
—— refining	666
—— roasting	668
—— sludge	668
—— smelting	665
—— smiddum	664
—— washing	663
Lecchi, Antonio	206
Let-off for water	564
Leupold Theatrum	962
Levels, variety of	736
——, gunners'	736
—— instruments for	793
—— lines	736
—— to rectify	795
—— used by the Romans	166
Level cutting on canals	1534
Levelling, compound	799. 802
Levers used by the Romans	201. 928. 982. 997
——, with toothed wheels	982
Lias formation	629
Libra aquaria	166
Lichens which grow on stone	384
Lifts on canals	1555
Light, Beale's	1242
——, reflected	784
Lighthouses	64
Bell rock	341
Cape de la Heve	232
Cordouan	240
Eddystone	367
Isle of Man	342
Lowestoft	319
Menai	360
Northern	342
Pentland Skerries	342
Ramsgate	1229
Spurn point	329
Sunderland	335
—— lamps	861
Lignum vitæ wood	1287
Limaria	168
Lime 71. 78. 94.	717
——, wood of 100.	1287
Lime-kilns	
——, manufacture of	
Limestone	701
——, aymestry	632
——, carboniferous	631
——, magnesian	639
——, mountain	630
——, primary	633
——, scar	631
Lines, perpendicular	734
——, inclined	735
——, variety of 734,	735, 736
Links of Gunter's chain	846
Liquids, level of	1096
Lithium	651
Llandello flags	632
Loam, Windsor	710
Locomotive engines	301. 1272. 1282
Locks on canals 217.	222, 223. 1537
—— at Cherbourg	225
——, bridges	1559
——, cast-iron	566
——, centres of impression	1115. 1540
——, chambers of	1537
——, dimensions of	1540
——, gates of 232.	247. 326. 328
—— gates of iron	1553
—— on the Humber	327
——, scourer of sluice	1542
——, sections of	1538
——, stop gates	1557
——, talus to be given to walls of	1539
——, theory of	1535
—— to admit several boats	1537
——, towing-paths	1556
——, water enter	1558
——, water expended	1539
——, Zendrini's account of	187
Logarithms	860
Lombardy, stone of	95
London Bridge, contract for	455
Longitude	757
Looms for weaving	969
Lorenzo, St., gate of	93
Lorgna's centres	1395
——, Marco	206
Louchetté	1057
Lough Swilly and Foyle	542
Loutron or cold bath	122
Lubricating axles	1023
Lucrinus, lake of	140
Lugdunum	180
Luna, town of	143
——, marble	99
Luxor obelisk at Paris	1016
Lycia	76, 77. 82
Machines used by the Romans	200
—— of Ctesibius	204
—— for measuring distances	205
—— Cagnarel Latour's	959
—— Carberry's	999
—— centrifugal force	1166
—— Cessart's, de	1024
——, Morel's,	1191. 1208

Page
Machines, Verra's - 1165
—— Vialon's - - 1166
——, brick-making - 711
——, construction of 1565
——, disengagement of - - - 950
——, dressing flour 1048
——, effects of - 1188
—— elementary parts of - - 939
—— proving strength of materials - 1025
—— for punching - 1035
Maggiore, lake of - 186
Mahogany, wood of, 1287
Mains for supply of water - - 1214
Malton's perspective - 789
Mammalia in geology 620
Mammertine prison - 97
Man, daily labour of 1093
—— drawing and pushing - 1091
—— moving a load - 1089
—— moving winches 1090
Manfredi, Eustachio 206. 208
Manganese - - 655
Maple, wood of 100. 1287
Marble - - - 99
——, Alracian - 100
——, Barsenite - 100
——, Carrara - 99
——, Chios - - 100
——, forest - - 628
——, Lacedæmonian 100
——, Lydian - 100
——, mills for sawing 1044
——, statuary - 703
Markets - - 287
——, Givars, St. - 288
——, Germain, St. - 289
——, Martin, St. - 289
Marls, variegated - 629
Marshes, Linturna - 148
——, Pontine - 152
Masetto, Giovanbatista 206
Masonry - - 1419
——, Eddystone light-house - - 371
——, of London Bridge - - 450
——, valuation of the several kinds - 907
Materials, strength of 1025
Mausoleum of Adrian 99. 198
——, Augustus - 197
Mausolus, palace of - 54
Mean proportional - 766
Measurement of depths, &c. - - - - 815
Measures, ancient and modern - - 911
Mechanical agents - 1087
——, power, equilibrium of - - 939

Page
Mechanics - - 915
Mechelini, Famiano 206
Mediterranean Sea - 685
Meltuno, town of - 146
Menander crossed by Cyrus - - 67
Mengotti, Francesco - 206
Mensuration - 863
Mercury - - 656
Meridian, to determine - - 855
Messene, city of - 72
Metagenes - - 75
Mica, analysis of - 715
——, schist - - 633
Micænas, mole of - 142
Mickle's windmill sails 1220
Middleton, Sir Thomas - - - 545
Miliaria, or lead cisterns - - 129
Mills, hand and horse 1045
——, cement - 1029
——, dams - - 639
——, grinding corn - 1045
——, mortar - 1049
——, saw, for marble 204
——, water - - 203
Millstone grit, - 638
Millstones - - 1047
Minerals, their composition - - - 643
Mine, sinking shaft of 1063
Miners - - 675
Mines - 659. 661. 671
Mining instruments 1063
Miocene in geology - 624
Mirrors, how made - 732
Mole, constructed at Eubœa - - 67
——, at Misenus, 141. 142. 147
Mollusca - - 621
Montanari, Genunano 206
Morelatto raising ships 1054
Morice, Peter - - 544
Morland, Sir Samuel 582
Mortar - 455. 717. 1049
——, value of - - 906
Morton's mechanical slips - - - 347
Motion of fluids - 1126
Motions of machines, conversion of - 953
——, alternate rectilinear - - 992
——, circular alternate 973. 995, 996
——, circular continuous - 979. 987
——, parallel motion 1263
——, cycloidal - 1266
Mouldings of Greek temples - - 758
Moulds of arches, development of - 1455

Page
Movements of machinery how calculated 982
Mud boats - - 329
Mulberry, wood of - 101
Multilateral figures - 771
Mural circles - 809
Muriatic acid - 647
Muro Torto at Rome 87
Musical strings, their vibrations - - 766
Mycenæ - - 67
——, treasury of - 79

Naples, Bay of - 138
Narcissus, employment of - - 195
Narducci, Tommaso 206
Nasmyth, James, on tools - - - 1033
Neapaphos - - 51
Neapolis - - - 57
Nero, circus of - 119
——, antico marble - 100
Newcomen, Thomas 582
Niches, hemispherical 1462
——, at an angle - 1462
Nicholson, Peter - 777
Nickel - - - 656
Nippers for cutting piles - - - 995
Nisida, Isle of - 139. 142
Nismes, walls of - 90
Nitrogen or azote - 644
Noble's suction pump 992
Nonagon - - 744
Norma - - - 72
Norman architecture 1603
Notching in carpentry 1304. 1307
Nymphenburgh machine - - - 1191

Oak, wood of 100. 1287
——, strength of - 1295
Obelisks, manner of conveying - 38
——, of elevating - 1013
——, single blocks - 39
——, at Alexandria 39
——, Arles - - 39
——, Axum - - 39
——, Cavallo - - 40
——, Cœlian Hill - 40
——, Citorio, Monte 40
——, Constantinople 39
——, Flaminio-del Popolo - 39
——, Jebel Barkal - 39
——, Luxor - - 39
——, Maria Maggiore 39
——, Medinet el Faioum - - 39
——, Minerveo della Minerva - 40
——, Navona, Piazza of - - 40

	Page
Obelisks, Pantheon	40
——, Pincio, Monte	40
——, Sallustiano della Trinita	40
——, Vatican	39
——, Whitaw Eskdale	1013
Ocha, quarries at	100
Ochre, red	103
Octares, boats	137
Octaedron	889
——, to construct	778
Octastyle proportions	1582
Oil gas	1242
Olive, wood of	101. 1288
Onctuarium	121
Oolite	627. 701
——, Bath	628
——, inferior	628, 629
——, middle	628
——, Portland	627
Optical square	843
Opus incertum	98
——, reticulātum	98. 1420
Orchomenos	79
Ordinates	735
Organic remains	620
Ostia, Basilica at	100
Ovals	749. 876
——, to reduce to a circle	88
Oxygen	644
Pacey, Whin	348
Paddles	188. 218. 1550
Pæonius	75
Paddle wheels, Roman	205
Painters' work, pieces of	910
Palæozoic in geology	623
Palæstra	130
Palladio	211
Palling the capstan	206
Palm	101
Pantheon, roof of	1332
——, portico of	1591
Pantograph	991
Paoli, Pietro	206
Parabola	750. 758
Paraboloid	757
Parallel lines	735
Parallelogram	760. 880
—— of forces	919
Parallelepipedon	888
Parian marble	99
Parthenon, proportions of	1584
Partitions, framed	1310
Pavements, Roman	101, 102
Pedal	981
Pelasgi	68
Pen, geometric	990
Penara, gates of	76
Pendentives of vaults	1466
Pendulum	981
Penstock, ancient	194
Pentadoron	708
Pentagon	743. 879. 886
Pentaspastos	200
Pentelican marble	99
Pentrough	1150
Pephasmenos	75
Pepperino stone	95
Perea, Carli	206
Perelli, Tommaso	206
Perronet, Jean Rodolphe	266
Perspective	789
——, isometrical	791
Perugia, gate of	90
Perry, Captain John	398
Pertuis or sluices	188
Phalasarina, city of	51
Phalerum	43
Pharos	133. 146
Philopater, ship of	137
Phosphorus	648
Phrygian marble	100
Piers of bridges	1506
—— of cathedrals, their form	1624
Piers	132. 314. 320. 397, 398. 434. 557
Pile-driving	327, 328. 423. 465. 967. 1070
——, drawing	1078
——, cutting off	1080
Pilæ, or moles	140
Pile worm, (Teredo navalis)	1291
Pinchbeck	671
Pincian gate	87
Pine, yellow,	101. 729. 1286
Pinning in carpentry	1304
Piombino, Stephano del	163
Pipes of earthenware, &c.	167
—— stone	1427
—— for baths	123
Piquets	805, 806
Pisa Cathedral	1012
—— baptistery	1618
Piscina, remains of	63
—— limaria, &c.	168
—— mirabile	142
Pisé, manner of building	725
Pistons, their construction	1258
——, strength of	1257
——, varieties of	1259
Pit cranes	1006
Pitch tree	101
——, manner of making	729
——, lines of wheels	941
——, prices of pitching	911
Pitot's centres	1406
Placoidans	621
Plane, epicycloid	940
Plane table	835
—— to measure with	836
—— to map with	840
Planeometry	733
Planing, machine for	1039
Planking and piling, value of	899
Plans, to draw	737. 864
——, to copy	870
——, ichnographic	760
——, orthographic	760
——, scenographic	761
Plants, fossil	622
Plaster, machine for beating	968
Plate glass	731
Platform of timber for sluices	219
—— of locks	1542
Platinum	658
Platonic bodies	889
Pliocene in geology	624
Plungers of wood	1180
Poikilitic formation	629
Points of support	118
——, varieties of	733
Poleni, Giovanni	208
Poleri, Giovanni	206
Poliphele, arch of	1595
Polygons	743, 744. 755. 879
Polyhedrons	754
Polyspaston	201
Pomærium	85
Pontoons	231. 1054
Pontou Gephura	66
Ponts et Chaussées	215
Poplar wood	100. 1288
Porosity	915
Porcelain, grinding for	975
Portes busquées	218
Ports and harbours —	
Aberconway	360
Aberdeen	343
Aberystwith	362
Adria	138
Agrigentum	60
Alexandria	32
Ancona	145
Androssan	367
Antium	145
Arbroath	342
Aubin's, St.	402
Avoch	350
Axmouth	385
Ayr	358
Baiæ	139
Baltimore	294
Banff	350
Bangor	360
Barnstaple	363
Barton on Humber	324
Beaumaris	360
Berwick on Tweed	337

Ports and harbours — Page
Bideford - 363
Birkenhead - 360
Bordeaux - 237
Boston, America 293
Boston - - 224
Bridgewater - 363
Bridlington - 332
Bristol - - 363
Brundusium - 147
Burghhead - 349
Byrsa - - 6
Caernarvon - 360
Cardiff - - 362
Carlisle - - 369
Carthage - - 5
Centocellæ - 133
Charlestown - 296
Chios - - 50
Civita Vecchia - 137
Claudius - - 134
Cnidus - - 32
Cordouan - 240
Corinth - - 44
Cork - - 401
Corran - - 367
Cothon - - 6
Cromarty - 352
Cullen - - 351
Cuma - - 139
Cherbourg - 223
Christchurch - 385
Crete - - 51
Cuxmere haven 387
Cyprus - - 51
Dartmouth - 385
Delos - - 51
Dieppe - - 235
Douglas - - 396
Dover - - 389
Dublin - - 398
Dunbar - - 337
Dundee - - 339
Dunkirk - - 218
Egina - - 45
Eleusis - - 43
Ephesus - - 51
Exmouth - - 385
Eyemouth - 337
Falmouth - 364
Feoline - - 356
Findhorn - - 349
Folkestone - 389
Fortrose - - 351
Fowey - - 364
Frazerburgh - 349

Genoa - - 143
Glasgow - - 357
Goole - - 324
Gourdron - 342
Gravelines - 322
Greenock - - 357
Grimsby - - 324
Halicarnassus - 53
Halifax - - 293

Ports and harbours — Page
Hampton (Little) 386
Hartland - - 363
Hartlepool - 332
Harwich - - 319
Hastings - - 387
Havre de Grace 232
Holyhead - - 361
Howth - - 399
Ilfracombe - 363
Isene - - 48
Ive's, St. - - 363
Jersey - - 401
Jura, small isles 356
Kingston upon Hull - - 325
Kingstown - 460
Kirkwall - - 353
Kyle - - 353
Lancaster - 359
Leghorn - - 142
Leith - - 338
Liverpool - - 359
Lyme Regis - 385
Lynn, King's - 322
Mahomac - - 352
Margate - - 396
Marseilles - 237
Megara - - 6
Messina - - 64
Milford Haven - 362
Miseno - - 139
Misenus - - 142
Montreal - - 293
Montrose - - 342
Munychia - 41
Myndus - - 55
Naples - - 138
Newhaven - 387
Orford - - 319
Orkney isles - 353
Orleans, New - 294
Ostia - - 133
Padstow - - 363
Palermo - - 56
Paros - - 51
Penzance - - 364
Peterhead - - 358
Phalerium - 41
Philadelphia - 296
Piræus - - 41
Plymouth - - 364
Poole - - 385
Port Patrick - 397
Portsmouth - 386
Posidonia - - 65
Pozzuoli - - 139
Pulteney town - 352
Quebec - - 293
Ramsgate - 392
Ravenglass - 359
Ravenna - - 138
Rethymna - 51
Rhea - - 354
Rhodes - - 45
Rimini - - 138

Ports and harbours — Page
Rochefort - 238
Rouen - - 239
Rye - - 387
Salamis - - 44
Salines - - 51
Samos - - 49
Sandwich - - 592
Scarborough - 332
Selinus - - 63
Shoreham - 386
Sidmouth - 385
Sidon - - 2
Smyrna - - 50
Southampton - 386
Southwold - 319
Spezzia - - 143
Stonehaven - 243
Sunderland - 335
Swansea - - 362
Syracuse - - 57
Tabermory - 355
Tain - - 352
Tarbut, East - 355
Tarentum - - 146
Tenedos - - 49
Teos - - 50
Terracina - - 137
Toulon - - 238
Trajan, port of - 133
Treport - - 233
Tripoli - - 5
Troas - - 49
Troon - - 350
Tynemouth - 336
Tyre - - 2
Venice - - 144
Watchet - - 363
Wells - - 320
Weymouth - 385
Whitby - - 382
Whitehaven - 359
Wich - - 352
Wisbeach - - 324
Workington - 359
Yarmouth - 320
York, New - 296
Populunia - - 77
Port crayons - - 868
Posilippo, grotto of - 139
Posts, king and queen 1309
——, bearing - - 1308
Potassium - - 649
Power, mechanical - 919
——, producing motion - - 1143
Pozzolana - 92. 95
Pozzuoli, mole of - 95
Prænestine roadway - 149
—— camp - - 93
Press, hydrostatic - 1026
Pressure on vaults - 706
——, centres of - 1114
Prisms - - 755. 888
Prisons - 601, 602, 603
Procida - - - 139

	Page
Projection of globes	783
Prony's machine	969
Property, how to value	891
——, houses	893
——, mills	894
——, soils	892
Proportionals, various	766
Proportions belonging to architecture	1579
Propylons	30
Protraction of lines	839
Protractor	748
Pseudisodomum	1422
Pug mills	709
Pulleys, 201. 930. 936, 937. 999	
Pumice-stone	95
Pump-barrels	1186
Pumps, 207. 1169.	1279
——, cellular	1197
——, chain	1196
——, forcing 1169.	1174
——, foundations to clear	1204
——, Franklin's	1174
—— Hedderwick's	1173
——, ship	1175
——, suction 207. 1170.	1174
Pterepoda	621
Punching machines	1034
Purbeck marble	627
Purifying apparatus	552
Purple colour	100
Pyramids of Egypt	9
Abou Roash	23
Abou Seir	23
Biahhmoo	29
Dashoor	27
El Koofa	29
Ethiopian	29
Geezeh	9
Gibel el Birkel	31
Howara	29
Ilahoon	29
Lisht	28
Meroe	29
Meydoom	28
Mycerinus	14
Nouri	31
Reegah	23
Saccara	24
Zowyet el Arrian	23
Pyramid, great, solid contents of	10
——, passages and galleries	11
——, second, dimensions of	13
——, third, dimensions of	14
——, inclined passages	15
Quadrant	749
——, Hadley's	845
Quadrilateral figures	742
Quadriremis boats	137
Quarries in Egppt 36, 37, 38	
——, Baruthel	116
——, of granite	348
——, marble	143
——, Roquemaillere	116
Quartz	704
Quay walls 223. 238, 239.	1518
——, of earth and timber	293
Quinqueremes boats	137
Quirium, city of	85
Quoins of lock gates	1548
Radiata in geology	621
Radii of wheels	943
Railroads	1566
——, chairs	1572
——, curves given to	1574
——, cutting	1567
——, edge rails	1571
——, embankments	1667
——, excavations	1567
——, foundations for sleepers	1569
——, gradients	1568
——, passing rails	1576
——, planes on	1578
——, plate rails	1571
——, rails, various	1571
——, rails, their form	1871
——, sleepers	1569
——, stone blocks	1569
——, switches	1577
——, turn tables	1575
——, width between rails	1568
Railroads in America	300
Belgium	292
England	584
France	292
Germany	292
Allegany and Portage	304
Altona	292
Atlantic, Great	301
Ballochney	588
Baltimore and Wheeling	301
Berlin and Potsdam	292
Berwick and Kelso	586
Bolton and Leigh	589
Boston and Buffalo	300
Boston and Lowell	301
Boston and Providence	302
Braine la Compte to Namur	292
Brandling Junction	592
Railroads—	Page
Breslau and Friburg	292
Bridgend	589
Bristol and Gloucestershire	589
Brunswick and Hanover	292
Brussells and Antwerp	292
Brussells and France	292
Budweis	292
Bullo Pill or Forest of Dean	586
Caermarthenshire	586
Camben and Amboy	302
Canterbury and Whitstable	589
Carlsruhe	292
Charlestown and Ohio	301
Clarence	589
Cologne and Aix la Chapelle	292
Cologne and Bonn	292
Columbia and Philadelphia	303
Cromford and High Peak	587
Croydon, Merstham, &c.	586
Dublin and Kingstown	589
Duffryn Llynvi	588
Dulais	588
Dundee and Newtyle	588
Durham and Sunderland	587
Dusseldorf and Elberfeld	292
Edinburgh and Dalkeith	588
Frankfort and Wisbaden	292
Garnkirk and Glasgow	588
Gemunden	292
Germains, St.	292
Ghent to France	292
Gloucester and Cheltenham	587
Grossmont	587
Harlem	302
Hay	586
Heck and Wentbridge	589
Hull and Selby	592
Jersey, New	303
Johnstan and Ardrossan	589
Junction, Grand	589
Kiel	292

Page

Railroads —
Kilmarnock - 586
Kingston - - 587
Leeds and Selby 589
Leicester and Swannington - 589
Leipsic and Dresden - 292
Liverpool and Manchester - 589
Llanelly - - 589
Llanfihangel - 586
London and Birmingham - 590
London and Croydon - 592
London and Greenwich - 589
Long Island - 302
Lothian, West - 587
Magdeburg - 292
Malines to Ostend - - 292
Malines to Prussia - - 292
Mamhilad - - 587
Manchester and Birmingham - 591
Manheim - - 292
Mansfield and Pinxton - 587
Monkland and Kirkintilloch - 587
Monmouth - 586
Montpellier and Cette - - 292
Mulhausen and Tham - - 292
Nantle - - 588
Newcastle and Carlisle - - 590
Newcastle and Darlington - 590
Norwich and Worcester - 302
Nurembourg and Furth - 292
Oystermouth - 586
Paris and Orleans 292
Paris and Rouen 292
Penrhynmaur - 587
Philadelphia and Erie - - - 300
Plymouth and Dartmouth - 587
Portland - - 580
Portsmouth and Pensacola 300
Preston and Wyre - - 592
Providence and Stonington - 302
Redruth and Chasewater - 587
Richmond and Covington - 301

Page

Railroads —
Rouen and Havre 292
Rumney - - 587
Severn and Wye 586
Sirhowey - - 586
Stevens, St., and Lyons - - 292
Stockton and Darlington - 587
Strasburgh - 292
Stratford and Moreton - 587
Surrey - - 586
Union, North - 592
Versailles - - 292
Vienna and Gloggnitz - 292
Warrington and Newton - 589
Western, Great - 591
Western, South - 591
Wishaw and Coltness - 589
York and Albany 302
Ramming earth - 897
Rams, hydraulic - - 1109
——, at Marly - 1162
——, Montgolfier's - 954
——, siphon - - 1161
——, suction - 1161, 1566
Ratchet lever - - 982
Ravenna - - - 206
Receptaculum for water - - - 172
Recipiangle - - 864
Recoil escapements - 983
Rectangle reduced to triangles - - 878
Rectilinear figures and motion 202, 880, 883
Reflected light - - 243
—— circle - - 809
Regemont, M. - - 246
Regular solids - 778
Regulator box - 1274
Rennie's, George, experiments - - 1026
——, Buchanan - 1002
Repeating circle - 810
Repose - - - 916
Reptiles - - - 621
Reservoirs - - 60
—— for baths - 123
—— of locks - - 1557
Resin - - - 728
Resistance of materials 1026
Rhedæ - - 1015
Ridge and hip tiles - 711
Riding-house at Moscow - - 1335
Right and oblique cylinders - - 780
Rimini - - - 206
Ring, circular - - 875
——, cylindrical 749. 890
Risban at Dunkerque 217

Page

Rivers, Alabama, &c. 293
——, origin of - - 638
——, method of crossing 66, 67
——, the Rhone, &c. 642
——, walls - - 1525
Riveting - - 1035
Rocks, Kelloway - 628
——, Ludlow - - 632
——, Plutonic - - 654
——, Quartz - - 653
——, Yaredale - 631
Roads, in France - 216
——, Roman - 149. 523
——, laid out by Perronet - 267
——, materials for making - 150
——, names of - - 151
——, parish - - 524
——, specifications for making - 526
——, timber - - 516
Rollers, eccentric - 1261
——, friction - - 952
——, spherical for bridges - 1392
Roman cities and towns, walls, towers, &c. 84, 85
—— wall at Hartlepool - - 333
Rondelet's table of the strength of oak 1294
Roofs trussed with iron 1332
—— ball room, Brussels - 1327
—— Christ Church Hall - - 1318
—— Crosby Hall - 1318
—— Eltham Hall - 1317
—— Hampton Court 1318
—— James's, St. church - 1332
—— Louvais - - 1322
—— Mansard's - 1319
—— Odeon - - 1331
—— of large span - 1344
—— of timber - - 1332
—— Opera des Arts 1328
—— Palais Royal - 1322
—— Pantheon, Paris 1327
—— Paul, St., Rome 1329
—— Riding house, Moscow 1329. 1335
—— Theatre of Bordeaux - - 1324
—— Theatre Italian, Paris - - 1326
—— St. Martin 1323
——, tie-beams, experiments on - 1319
—— with hozirontal ties - - 1334
Rope ladders - - 1569
——, rigidity of - 1418

Page

Roslyn Chapel, proportions - - 1618
Rosso antico - - 703
Rotæ machines - 1015
Rouen, quay wall at 1528
——, Cathedral windows, proportions of - 1612. 1613
——, St. Ouen at - 1616
Roughton Gill mine 664
Rubble work, value of 907
Rudder, Roman - 202
Rudyard, John - 368
Rules, parallel - - 763
Running water, experiments on - 1138

Sabbadino Christopher - - - 209
Sabinum - - - 83
Sacbuts used at Syracuse - - - 58
Sails of windmills - 1219
Salisbury cathedral - 1603
Sallust, circus of - 119
——, gardens of - 93
Salopians - - 84
Samaritaine - - 255
Samnites - - 83
Samos ware - - 49
Sand used by Romans 94
—— banks - - 642
—— green - - 626
—— for mortar - - 723
Sandstone - 629. 631. 698
Savo, river of - - 148
Saxon architecture - 1601
Scæan gate, with mole - - - - 72
Scaffolding - - 1410
—— made of spars - 1013
——, Mandar's design 1413
—— of Pantheon - 1416
——, value of - 900
——, Zabaglia's - 1414
Scalding houses - 286
Scale, manner of dividing - - - 733
Scarfing timber 1304. 1307
Schist, chlorite - 633
——, hornblende - 632
——, talcose - - 633
Sciography - - 785
Scipio Africanus, bath of - - - 125
Scouring sluice 1559. 234
Screw - - - 1214. 1566
——, Archimedian - 1167
—— bolts, machines for - - 1028
—— docks - - 294
——, endless or perpetual - - 927
——, jacks - - 1002
——, mill and press - 955

Page

Screw-cutting machine 991. 1037
Sea banks - - 542
—— lock at Dunkerque - - 217
—— wall at Brighton 1526
—— wall at Dimchurch - - 1558
—— water - - 636
—— waves - - 636
Seasoning timber - 1289
Seats in amphitheatres 114
Secants of an angle - 856
Sectants - - - 844
Sectors - - - 749
——, uses of - - 819
——, to find the area of - - 875
——, to measure heights with - 825
Sediments, argillaceous - - - 624
Segments, to find area of - - 875
——, of spheres - 876
Selce, stone for pavements - - - 95
Selenium - - 648
Self-acting slide rest - 1030
Semicircles - - 748
Semita, or foot-road - 149
Sepulchres cut out of rocks - - - 82
——, Roman - - 196
Seradifalco, Duca di - 80
Serpentine, its composition - - - 635
Servius, wall of - 86
Setting out lines - 793
Sewers - - 83. 192
——, commission of 543
——, Roman - - 191
Shackles, chain and screw - - - 1023
Shadows - - - 784
Shafts, or axles - 945
—— of cast-iron, strength of - 945
——, sunk for tunnelling - 184. 194
Shales, limestone - 630
——, upper lias - 629
Shears for cutting iron - - - 1037
Sheds for ship-building - - - 1343
Sheeting-piles - - 1075
Sheets of iron, punching - - 1035
Shield for tunnelling 1560
Ships, Roman - - 137
——, loaded, manner of lifting - 294
——, loading and unloading - 201
——, sunken, to raise 1054

Page

Sides of triangles, how to calculate - - 854
Sieves, machine to move - - - 995
Sight, point of, in perspective - - 790
Signals - - - 854
Siliceous - - 698
Silicium - - - 654
Silk-twisting machine 976
Silurian in geology - 622
Silver - - - 657
Sines - 761. 793. 856
——, to find arcs of - 857
Sinuessa on the Domitian road - - 148
Sipho for extinguishing fire - - 167
Siphon for draining - 1098. 1164
Skew back of arches - 1430
—— bridges - - 471
Skins inflated to cross rivers - - - 67
Slate, Stonesfield - 628
Slides in geology - 619
Slips, inclined planes for ships - - 239
Sloping beaches, their advantages - - 345
Slotting machines for 1037
Sluices of cast-iron - 326
Sluices, 217, 218, 219. 220, 223, 1558
——, for scouring harbours - 391. 394
——, side walls of - 218
——, at Turner's and Bergue's - - 219
Smeaton, John, memoir of - - 429
——, diving-bell of - 1051
——, hand-pump of - 1175
Smelting and refining 34
Smoothing iron, machine for - - 1040
Sodium - - - 650
Soldering the metals 167
Solids, how to construct - - - 776
——, mensuration of 888
Sophia, St., at Constantinople - - 100
Sopwith's levelling staves - - 799
Sounding the soil - 1519
—— lines - - 850
Sources, machine at - 1190
Space - - - 916
Spandrill and wing walls - - - 1522
Spar, calcareous - 700
Specifications 415. 465. 468 526
Spello, gate t - - 88
Speluncas - - 148

Page

Sphere - 756. 876. 890
——, surfaces of - 747
Spherical valves - 1183
—— trigonometry - 778
Spheristerium 122. 130
Spheroid, or solid ellipse - - - 890
Spiral, to find area of 875
——, cylindrical, to draw - - - 789
Spirit levels - - 794
Spoliatorium - - 131
Spring balances, and of water - 165. 1067
Square, to draw 880, 881. 883
——, geometric, use of 817
——, to double - 883
——, to reduce 880, 881
Stadium - - - 122
Staircases 111, 112. 1469 1475
Stamping-mills for ore 664
Stand pipes, hoisting of 1012
Stateræ, Roman - 202
Station pointer 808. 850
Statutes of Romney Marsh - 532. 1242
Staves for levelling - 799
Steam as a moving power - - - 1260
Steam-engines, history of - - 581
——, application to mills - - 1270
——, atmospheric - 1243
——, Albion mills - 1248
——, double-acting - 1247
—— employed at the London docks 311
——, Hornblower's - 1250
——, locomotive - 1271
——, pumping - 327, 328
——, single-acting - 1245
—— used for pile-driving - 1084
—— used for bridge-building - 437
Steel - 686, 687. 689
—— yards - - 729
Stereometry - - 733
Stevenson, Robert - 470
Stierne's domes - 1346
Stone, 92. 95. 1020. 1425
—— blocks and sleepers 1572
—— laid without cement - - 178
——, machine for throwing, into sea - - 1024
Stone pipes - - 1427
——, polygonal blocks - - 68
—— quarries - - 697
—— quarries, wheels used at - 966

Page

Stone, resistance of, to the crush - 705
——, transport on boats - - 367
Stoves and grates 1224
——, Dr. Arnott's - 1221
——, metallic - - 1224
Strade at Hastings - - 387
Stratification - - 623
Strike in geology 619. 623
Strontium - - 652
Stucco, tempering - 102
—— in damp places 103
Sublimation - - 916
Subsoil, drainage of - 1559. 1563
Sulinis Minerva, altar to - - - 130
Sulphur - - - 647
Sunderland light-house, removal of - 335
Superficies - 759. 877.
Supply of water in France - - - 285
——, America - - 297
Surveying, cross - 843
——, maritime - 849
——, parish - - 848
——, subterranean - 832 849
Suspension bridges - 507
Suspensura floors 122. 127
Swape - - - 331
Swing bridges of iron 521
Sydma, gate of - - 76
Syenite, composition of - - - 634
Symmetry - - 1595

Tabularum - 96, 97
Tandini, Antonio - 206
Tangential force machine - - - 1067
Tangents - - - 857
Taorminum - - 64
Tar, how obtained - 728
Tatian marble - - 99
Teeth of wheels, their curve - - - 940
——, pitch line - 941
——, strength - - 942
——, thickness - 944
Telegraph, electric - 599
Telescope - - 207
Telford, Thomas - 469
Temples, façade of - 1581
—— Antoninus, &c. - 96
Ægesta - - 64
Castor and Pollux - - 63
Fortuna Virilis - 97
Hercules - - 63
Jupiter Capitolinus - - 99
Jupiter Olympus, 61, 62

Page

Temples, Jupiter Panhellenius - 45
Minerva - - 61
Romulus - - 98
Vesta - - 98
Tenons and mortises - 1305
Tepidarium - 121. 131
Teredo navalis - 1291
Terracina - 138. 148
Tertiary series in geology - 622. 628
Testudines used at Rhodes - - 47
Tetradoron - 708. 755
Tetraedron - - 889
——, to find solidity - - - 889
Tetrastyle proportions 1580
—— temples - - 1581
Thames river - - 307
Theatres - - - 107
—— of the Romans - - 106
——, of Marcellus - 107
Theodolite - 840. 842
Thermæ, Adrian's - 120
Alexander Severus - - 120
Antoninus and Caracalla - 120
Antoninus - - 94
Aurelian - - 120
Commodus - 120
Constantine - 120
Decus - - 120
Diocletian - - 120
Domitian - - 120
Nero - - 120
Philip - - 120
Pompeii - - 128
Titus - - 120
Trajan - - 120
Thermolousia - - 131
Thermometer discovered - - 207
Thomasin - - 246
Threads, double cutting of - - - 1038
Tide gauges - - 849
—— currents - - 636
—— mill - - 971
Tiles, 94. 711, 712, 713
Timber, varieties of - 100. 1285
——, cohesive strength of - 1293
——, decay of - 1289
——, felling of 100. 1289
——, resistance of - 1294
——, strength placed vertically - 1303
——, strength, inclined 1303
——, transverse strains - - 1292
——, waste of - 904
Tides, their effect - 322

Page
Tides of the sea - 636
——, their force - 229
——, of the atmosphere - - 637
Tile-kiln - - - 730
Tiles, draining with - 1564
——, ornamental - 713
Timber bridges - 1350
——, principles of - 1350
——, platform for sluices - - 219
——, value of - - 902
Tin - - - - - 670
Tomb of Archimedes 777
—— at Agrigentum - 80
—— of Alexander Severus - 200
—— of Cecilia Metella - - 97
—— of Romans - 199
—— of Scipios - 93
—— of Telmessus - 77
—— of Theodoric - 206
Tools used in lead mines - - 661
—— of miners - 675
Torni, machines - 1015
Torricelli, Evangelista 207
Tour de Corduan - 237
Towers of Roman walls - - - - 87
Tracery of Gothic windows - - 1608
Tracing lines on the ground - - 762
Tractoria, machine - 1015
Trajan's Column - 198
Trapezium - 743. 878
Trapezoid - - 743
Travertine stone - 95
Treasuries of Greece 79
Trenches cut by Greeks - - 66
Tres Taburnæ - - 148
Trevithick, Richard - 583
—— engine - - 1175
Triangles - - 741
——, sides of - - 854
——, to divide - 884
——, to form - - 769
——, to measure - 872
——, to reduce - 878
Triangulations for surveying - - 812
——, to draw one similar to another 769
Trigonometry - 733. 803
——, surveying - 852
Triremis or Roman boats - - - 137
Trispastos for raising weights - - 200
Triumphal arches, proportions - - 1596
Trompe, to construct 1454. 1464.

Page
Troughton's improved level - - - 796
Trucks with wheels - 1019
Trypho - - - 75
Tubuli fictiles - - 167
Tufa stone - - 95
Tumuli - - - 197
Tunicata - - - 621
Tunnel, Thames - 522
——, centres for - 1405
——, for cleaning harbours - - 840
—— in chalk - - 574
—— for scouring docks - 359
Tunnelling by Romans 166. 193
Turf, laying down - 897
Turning gates of sluices 220. 232. 234
Turn tables - - 1577
Turpentine - 729, 730.
Tusculum - - 77
Tympanum, Roman - 202

Umbria - - 83
Unharnessing an animal, machine for - 970
Unit of labouring force 918
Universal joint - 1569
—— windmill - 958

Val St. Pierre, machine at - - 1192
Valves - 1179. 1182. 1259.
——, crown, rotary &c. 1260
——, cocks - - 1260
——, eccentric - 1262
——, opened by weights - 1261
——, safety - 1256. 1275
——, sliding - 1239, 1240
Vanvitelli - - 145
Vauban's works - 217
Vauloüé, James - 422
Vaults, conical - 1429
——, conoidal - 1465
——, cylindrical 753. 1429
——, descending and intersecting - 1441
——, flat - - 1430
——, Gothic, their construction - 1448
——, Gothic with ribs 1448
——, groined - 1444
—— hexagonal - - - 1445
—— hemispherical - 1460. 1461
——, hexagonal - 1446
——, keys of ditto - 1449
——, skewed and splayed - 1459
——, spheroidal - 1464
——, spherical - 1459
Veins in geology - 618

Page
Velarium or covering 117
Velocity of a river, how ascertained - 640
—— of a current - 1139
Venice, city of - 211
Vent pipes for aqueducts - - 181
Ventilation 181. 612. 675. 1228
Ventilators and blowers - - 1222
Verd and Bonne Esperance forts - 217
Verdigris - - 104
Verzy's steam-engine 958
Vermilion - - 103
Vermuyden, Cornelius 536. 539
Vessels, sunken, raising of - - 1054
Vestini, country of - 83
Via, or common road 149
—— Appia - - 151
—— Domitiana - 148
—— Flaminian - 149
—— Prænestine - 152
—— Sacra - - 85
—— Ulpian or unpaved - 151
Viaducts - - 303
Victualling yard, Deptford - - 814
View, point of, in perspective - - 790
Vis St. Gilles staircase - - 1470
Visual rays in perspective - - 789
Vitruvius - 83. 166
Vivarium, remains of 97
Volterra, walls at - 77
Voute d'Arete 1430. 1450

Waggons used on railways - - 1020
—— used in mines 1018
Walls, Aurelian's - 88
—— built by the Greeks around their cities - 75
—— of cities - 67. 83
—— of crude brick - 36
——, double, of Greek cities - - 76
——, Chester and Winchester - 407
——, London and York - - 403
——, Rhine to Danube - - 86
——, Servius Tullius 86
——, Southampton and Rochester - - 408
——, sea - 1525, 1526
Walnut, wood of - 1288

Page
Warming and lighting 1223
—— apartments in Paris - - 132
—— by air - - 1227
—— by hot water - 1225
—— by steam - 1227
—— new prison - 615
——, Persian method 132
——, Roman method 131
Water 165, 166. 552. 635
——, bodies plunged in - - 1153
—— circular and vertical - 1110
——, closets introduced - - 549
——, conducting - 166
——, cost of raising 1213
——, engines for raising - 1179
—— filters 550, 551, 552
—— gauges - - 533
——, machines for raising - 1201
——, measurement through tubes 1126
——, method of finding - - 165
——, motion of, in pipes - - 1139
——, motion of, in rivers - - 1141
—— on inclined surfaces - - 1107
—— pipes, wooden - 549
——, quantity discharged by rivers - - 642
—— screw - - 203
——, supply of 297, 298, 299
——, towns supplied 544. 1210
Water, vertical action of - - 1099
——, waste through orifices - 1128
—— wheels - - 1142
—— works established for supply of London 548. 550.
—— works at London Bridge - 442. 545.
Watt's experiments on canals - - 1142
Waves in a storm, force of - - 229
Weardale mines - 660
Weather tiles - - 711
Wedge, use of - 925
Wedging in carpentry - - - 1304
——, fox-tail - - 1306
Weights, tables of - 914
——, raising of 928. 999
Weirs, discharge of water - - - 1140
Wells Cathedral - 1604
Wells, Artesian 1059, 1060
—— sunk by Romans 167
—— at Sheerness - 318
—— for supply of water - - 553
Wenlock formation - 632
Westminster Abbey - 1608
Wharf cranes - - 1005
Wharfing of boards - 323
Wheel and axle - 938
Wheels, construction of - 944, 945
——, breast water- - 1153
——, bucket water- - 1198
——, drum water- - 1196
Wheels, fly - - 1268
——, overshot - - 1148
——, Persian - - 1196
——, scoop - - 1196
——, tide - - 1151
——, undershot - 1142
Wheel, sun and planet 1266
—— machines for cutting teeth 1039
——, velocity of - 1148
Wheelwork - - 1566
—— rotating round two parallel axes - - 939
Whistle, steam - 1279
White's pulley - - 933
White lead - - 104
Winchester Cathedral 1621
Windlass used by Romans - - - 201
Willow, wood of 101. 1288
Winstanley, Henry - 368
Wind produced by a fall of water - - 1151
Windmills - 956, 957
——, horizontal - 956
—— sails, effects of, 1221
Wipers applied to wheels - - - 979
Workmen's tools, their power - - 927

Xerxes' bridge of boats - - - 66

Zanotti, Eustachio - 206
Zendrini, Bernardo - 208
Zinc - - - 669
Zones - - - 760
Zuliani, Pietro - 206
Zureda's machine - 962

THE END.

00080280

Digitized with financial assistance from the
Government of Maharashtra
on 23 March, 2016